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Materiel Test Procedure 6-2-502
Electronic Proving Ground

U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

HUMAN FACTORS ENGINEERING

1. OBJECTIVE

The objective of this Materiel Test Procedure (MTP) is to provide methods of determining the appropriateness and effectiveness of human factors aspects of equipment design.

2. BACKGROUND

Human factors engineering was developed as a formal discipline during World War II for the purpose of matching the controls of complex military equipment to the capabilities and limitations of the human operator.

Human engineering is defined as the design of equipment, man-machine systems, and human tasks for the most effective human accomplishment of the job. Such engineering requires consideration of human characteristics such as anthropometrics, intellectual abilities, sensory capacities, mobility, muscle strength, basic skills, and the capacity for learning new skills. In military human factors engineering, the designer must consider human limitations imposed by the environmental conditions typical of military situations of use where the operator is often working under stress and fatigue.

Most of the considerable amount of research in human factors engineering over the past 25 years has been directed toward the engineering design of equipment rather than test and evaluation. It is necessary to perform engineering testing to determine the extent that human factors engineering principles are present in the completed design under simulated use conditions and to disclose any human factors problem areas that may still exist under those conditions.

3. REQUIRED EQUIPMENT

Equipment required for human factors tests will generally include the same types of equipment and instrumentation used in engineering tests of the item. Specific selections shall be made by the test officer and the human factors engineer based on the nature of the test item and the particular human factors aspects to be tested.

4. REFERENCES

A. MIL-STD-454(-), Standard General Requirements for Electronic Equipment.
B. MIL-STD-1472, Human Engineering Design Criteria For Military Systems.
C. HEL-STD-S-3-65, Human Engineering Design Standard for Missile Systems and Related Equipment, 1965.

D. HEL-STD S-4-65, Human Factors Engineering Requirements for the Development of U. S. Army Materiel, 1965.
E. HEL-STD S-1-63(-), Maximum Noise Level for Army Materiel Command Equipment, 1965.
F. Report of Human Factors Engineering Seminar, Conducted by Dunlap and Associates, Inc., USAEPG 1960.
G. Technical and Memorandum 13-65, Lighting Small Shelters and Interiors: Criteria and an Example, U. S. Army Human Engineering Laboratories.
H. SCL-1280(-), Design of Electronic Equipment for and System Installation in Shelters and Vans.
I. SCL-1787(-), Human Factors Engineering for Signal Corps Systems and Equipment, April 1969.
J. Chaikin and Chaillet, Report No. RC-S-65-1, DOD Standardization Program - Project 1410-0016, Engineering Practice Study - Human Engineering, Directorate of Research and Development, U.S. Army Missile Command, October 1965.
K. Human Factors Ratings in Design of Signal Corps Systems, Final Report, Contract DA 36-039-SC-78328, Applied Psychology Corporation for U. S. Army Signal Research and Development Laboratory, 1961.
L. An Index of Electronic Equipment Operability, Report of Development - Contract DA 36-039-SC-80555, American Institute for Research, 1962.
M. Woodson, Wesley E., Human Engineering Guide for Equipment Designers, Second Edition, University of California Press, 1966.
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O. Meister and Rabideau, Human Factors Evaluation in Systems Development, John Wiley and Sons, Inc., 1965.
P. Myers, L. B., et al, Guidebook for the Collection of Human Factors Data, HRB - Singer, Inc., January 1966.
Q. Chapanis, A., Research Techniques in Human Engineering, The John Hopkins Press, 1959.
R. McCormick, Ernest J., Human Factors Engineering, McGraw-Hill Book Company, Inc., 1964.
S. MTP 3-1-002, Confidence Intervals and Sample Size.
T. MTP 6-2-507, Safety.

5. SCOPE

5.1 SUMMARY

5.1.1 Human Factors Characteristics

The procedures contained in this MTP provide general guidance for determining the degree of compliance of the test item to MIL-STD-1472 or other preferred human factors engineering standards. The cumulative test results, together with the results of appropriate common engineering tests, will allow

an evaluation to be made of the degree to which the item under test conforms to accepted human factors design principles, and the suitability of the design at man-machine interfaces.

The subtests given in this MTP are to be performed on a selective basis as required for a specific item of equipment. A list of these subtests and the objective of each are provided as follows:

a. Control-Display Relationships - The objective of this subtest is to determine the degree to which the test item design contributes to ease of operation through incorporation of preferred display and associated control location relative to each other and to operational characteristics.

b. Visual Displays - The objective of this subtest is to determine the suitability of visual displays relative to type, size, location, readability, consistency, and operational characteristics.

c. Auditory Warning Devices - The objective of this subtest is to determine the suitability of auditory warning devices relative to human factors aspects and operational characteristics.

d. Controls - The objective of this subtest is to determine the suitability of controls relative to type, size, application, location, coding, consistency, and operational characteristics.

e. Labeling - The objective of this subtest is to determine the suitability, readability, and consistency of labeling used for critical markings, identification, and instructions.

f. Workspace Design and Layout - The objective of this subtest is to determine the suitability of workspace relative to location, size, accessibility, and configuration.

g. Operator Comfort and Lack of Interference - The objective of this subtest is to determine if operator comfort and lack of interference aspects are satisfactory.

h. Special Observational Tests - The objective of this subtest is to determine the cause of special human factors engineering problem areas noted during some phase of equipment operation or testing.

5.1.2 Common Engineering Tests

Human factors considerations relating to maintainability and workspace environment are not covered in this document since these subjects are treated in separate common engineering test procedures as follows:

a. MTP 6-2-504, Design for Maintainability.

b. MTP 6-2-516, Adequacy of Lighting, Ventilation, Air Conditioning, and Heating Equipment.

5.2 LIMITATIONS

The explanatory material and evaluation criteria presented in this MTP is necessarily limited to those general human factor design considerations which can be quite easily measured and assessed. No attempt is made to present

tests and experimental procedures for the measurement and analysis of the dynamic processes effecting operability and efficiency of the man-machine system. Such tests and experiments must be designed by a qualified human factors engineer for the particular equipment or system under test.

Where the criteria in this MTP vary from the criteria of the appropriate standard such as MIL-STD-1472, the standard shall be accepted.

6. PROCEDURES

6.1 PREPARATION FOR TEST

a. Select test equipment ideally having an accuracy of ten orders of magnitude greater than that afforded by the item under test, that is in keeping with the state of the art, and with calibrations traceable to the National Bureau of Standards.

b. Record the following information:

1) Nomenclature, serial number(s), manufacturer's name, and function of the item(s) under test.
2) Nomenclature, serial number, accuracy tolerances, calibration requirements, and last date calibrated of the test equipment selected for the tests.

c. Ensure that all test personnel are familiar with the required technical and operational characteristics of the item under test, such as stipulated in Qualitative Materiel Requirements (QMR), Small Development Requirements (SDR), and Technical Characteristics (TC).

d. Review all instructional material issued with the test item by the manufacturer, contractor, or government, as well as reports of previous similar tests conducted on the same types of equipment. These documents shall be kept readily available for reference.

e. Prepare record forms for systematic entry of data, chronology of test, and analysis in final evaluation of the test item.

f. Prepare adequate safety precautions to provide safety for personnel and equipment, and ensure that all safety SOP's are observed throughout the test and that the item has successfully completed MTP 6-2-507, Safety.

g. Prepare a test item sample plan sufficient to ensure that enough samples of all measurements are taken to provide statistical confidence of final data in accordance with MTP 3-1-002. Provisions shall be made for modification during test progress as may be indicated by monitored test results.

h. Ensure that arrangements for supporting and participating agencies, activities, and facilities have been made, and that all test personnel have been briefed on human factors engineering (preferably by a human factors engineer), the purpose of the test, and anticipated results.

i. Prior to beginning any subtest, verify that the equipment is aligned, if necessary, as specified in the pertinent operating instructions to ensure, insofar as possible, it represents an average equipment in normal operating condition.

6.2 TEST CONDUCT

6.2.1 Control-Display Relationships

a. Energize the equipment under test and operate under conditions of normal expected use.

b. Record measurements taken and detailed answers to the following questions based on the cumulative experience and observations of test personnel gathered over the entire period of the commodity test:

1) Are the highest priority controls and displays placed within optimum viewing areas? (See Table I and Figure 1).

Table 1. Viewing Angles for the Seated, Standing, and Supine Positions

Body Member Rotated	Direction	Lateral Angle* Opt.	Lateral Angle* Max.	Direction	Vertical Angle Opt.	Vertical Angle Max.
Head only	Left	0	60	Up	0	50
	Right	0	60	Down	0	50
Eyes only	Left	15	35	Up	0	25
	Right	15	35	Down	30	35
Head and eyes	Left	15	95	Up	0	75
	Right	15	95	Down	30	85

* In degrees from the line of sight, which is assumed to be horizontal. Any shift in the line of sight from the horizontal will rotate these dimensions by a similar amount.

2) Are emergency controls and displays placed in readily accessible positions within 30 degrees of the operator's normal line of sight?

3) Are emergency controls and displays located in the optimum areas in preference to primary controls and displays, when the nature of an emergency is so critical that emergency controls and displays <u>should</u> be given top priority in location?

4) Are secondary controls and displays (less important than primary ones but used periodically during normal operations) placed within the overall areas, but not necessarily within the optimum areas? Is their exact location determined primarily by association and proper grouping?

5) Are adjustment and calibration controls and displays that are used frequently before the operator begins his primary tasks or during convenient slack periods, given the lowest priority in assigned locations?

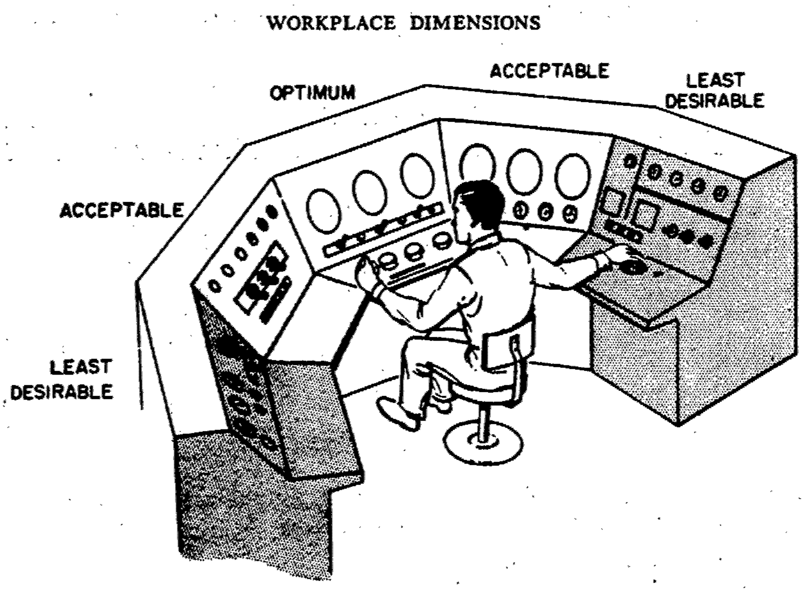


Figure-1. Optimum and Overall Manual Areas

6) If primary controls or displays must be used by two operators:

   a) Are duplicate sets provided whenever there is adequate space?
   b) If duplicate sets are not provided, are the controls or displays centered between the operators?

7) If secondary controls or displays must be used by two operators, are they placed between the operators?
8) Whenever direction-of-movement relationships are important and controls or displays must be shared by more than one operator, do the operators all face in the same direction?
9) When a control is always associated with a specific display:

   a) Is the control located so that the operator's hand does not block his view of the display?
   b) Are controls operated by the left hand located below or to the left of their associated displays (except that rotary controls should not be placed to the left of vertical displays)?
   c) Are controls operated by the right hand located below or to the right of their associated displays?

10) When a large number of displays are on the same panel, are they arranged in either of two ways as follows:

    a) Each display directly above its associated control; the control should be close to the displays so it cannot be erroneously associated with a display located below the control? (See A, Figure 2).
    b) All displays in the upper portion and all controls in the lower portion of the panel, with each control occupying the same relative position as its associated display? (See B, Figure 2).

11) When concentric (ganged) knobs are associated with displays, are the displays arranged in a row from left to right with the front (smallest) knob controlling the left display; the middle knob, the middle display; and the back (largest) knob, the right display? (See Figure 3.)
12) When rows of displays are associated with columns of controls, and vice versa, does left correspond with top and right with bottom? (See A, Figure 4).
13) When two or more rows of displays are associated with one row of controls, and vice versa, is the general arrangement shown in B, Figure 4, used?

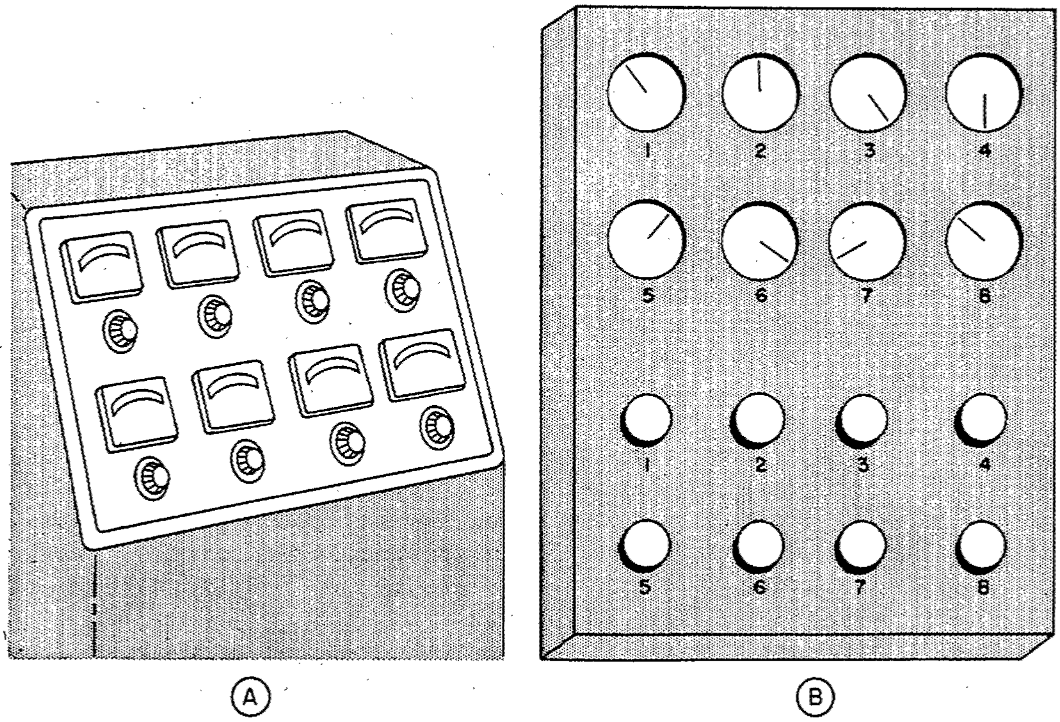


Figure-2. Two Methods of Control-Display Association

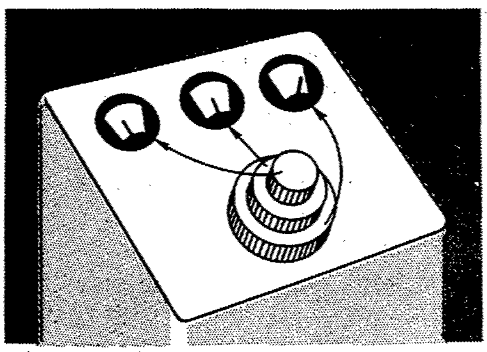
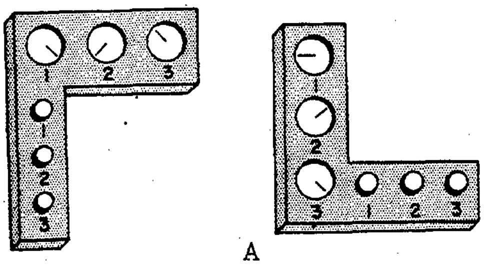
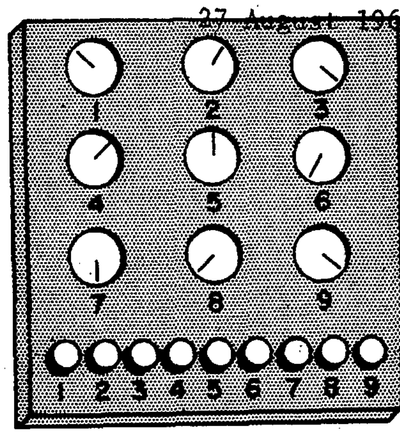


Figure-3. Concentric Knobs and Associated Displays



A



B

Figure-4. Association of Displays and Controls in Rows and Columns

14) With a rotary display that has a moving pointer and a stationary dial, does a clockwise rotation of the rotary control result in a clockwise rotation of the display pointer?

15) Are rotary controls on the concave sides of rotary displays when the display movement traverses less than a full circle? (See A, Figure 5).

16) When a rotary control and a linear display are in the same plane, does the part of the control adjacent to the display move in the same direction as the moving part of the display? (See B, Figure 5).

17) Are rotary controls located above any display or to the left of vertical displays?

18) When there is a direct linkage between control and display (e.g., the frequency knob of a radio):

a. Is a rotary control used if the indicator moves through an arc of more than 180 degrees? (See C, Figure 5).

b. Is a linear control used if the indicator moves through an arc of less than 180 degrees (provided that the path of control movement parallels the average path of the indicator movement and the indicator and control move in the same relative direction)? (See D, Figure 5).

19) Is the direction of linear control movements for on-off (or increase-decrease) controls, such as levers and toggle switches determined by the location of the panel on which these controls are mounted, i.e.:

a) For controls mounted on vertical panels, is "on" or "increase" an upward movement, "off" or "decrease" a downward movement?

b) For controls mounted on horizontal panels, is "on" or

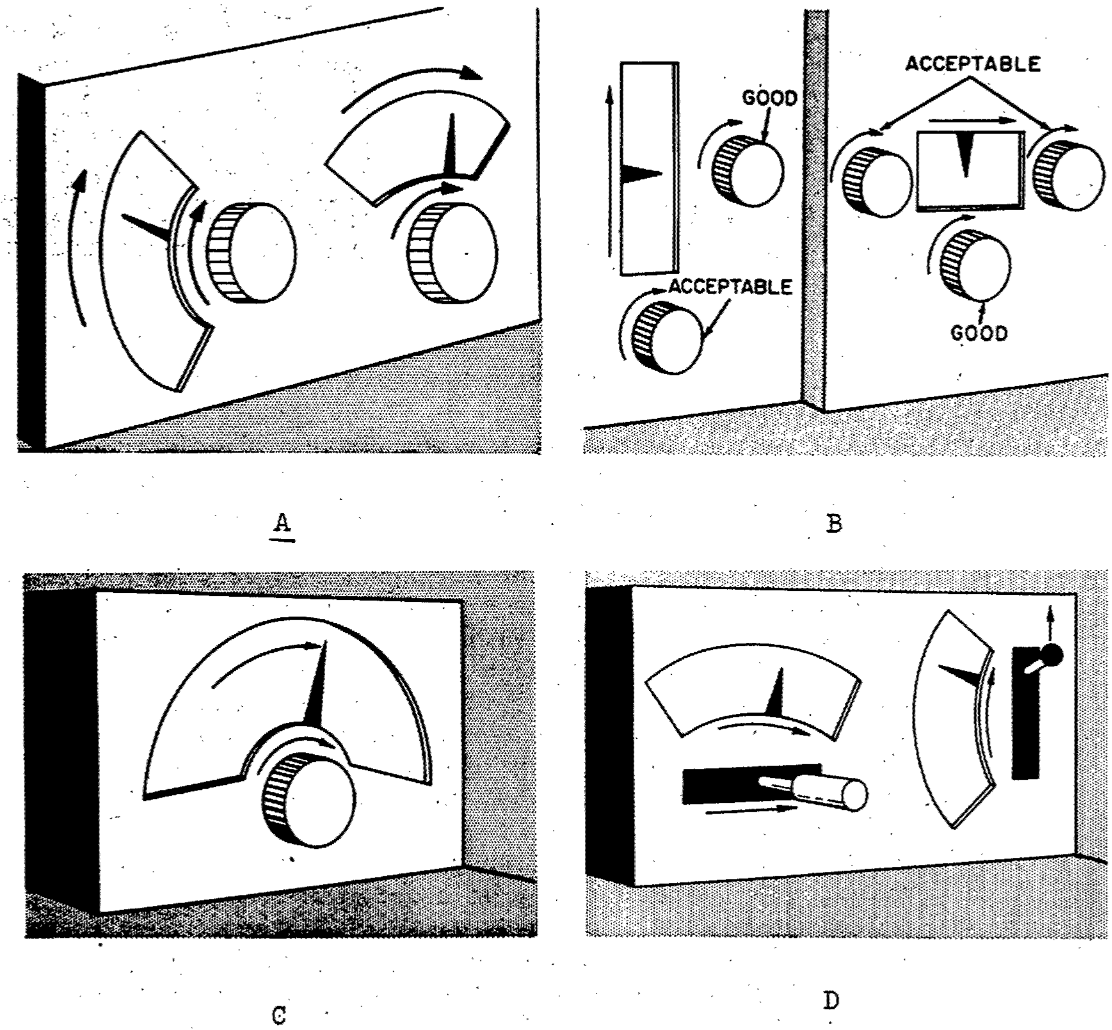


Figure -5. Control-Display Direction of Movement Relationship

"increase" a forward movement, "off" or "decrease" a rearward movement?

c) For overhead panels tilted less than 45 degrees from the vertical, are the controls actuated as if the panel were vertical and "on" or "increase" a forward movement?

20) Is functional grouping used when there is no definite sequence of operation and a number of controls or displays are used together in a specific task or are associated with a specific system component?

21) Is sequential grouping used when the operator must perform a definite sequence of operations? Does the sequential grouping permit observation and operation horizontally from left to right and vertically from top to bottom?

6.2.2 Visual Displays

a. Energize the equipment under test and operate in the normal expected usage mode.

b. Record measurements taken and detailed answers to the following questions based on the cumulative experience and observations of test personnel gathered over the entire period of the commodity test:

1) Are printed materials located at a viewing distance of approximately 16 inches except when indicators are designed for reading at arm's length (approximately 28 inches) to permit operator adjustment of controls?
2) For other reading distances, are display size and markings adjusted in direct proportion to the distance?
3) Are the sizes and scale markings of the display compatible with the level, type, and color of illumination, readable at the lowest expected level of illumination, whether floodlighting or some type of individual display lighting?
4) Are viewing angles 90 degrees to the plane of the display except on large panels, or where more than one person views the display? In such cases, is the design such as to compensate for parallax and prevent concealment of any part of the display?
5) When there are several displays, is each display easily identifiable and is there enough difference among the displays to preclude the operator reading the wrong one?
6) Are all displays and controls designed and located so that the operator, with little or no training, will select the correct control and operate it in the manner called for by the display?
7) Are indicators which present large differences in position, brightness, or color used where possible for discrete conditions (qualitative), such as in traffic lights?
8) Are counters used for precise numerical values (quantitative) when there is no requirement for interpolation between

numbers, rate, or directional information? Are scale indicators used when such values are to be "set into" the equipment?

9) Are scalar-type indicators used for numerical value plus orientation (check reading) in time, space, magnitude, or rate?

10) Are indicator scales designed:

   a) To be read as precisely as the operator needs to perform his task, but no more precisely?
   b) To be the least complex that fulfills the requirement?
   c) To present only that amount of information that the operator needs and no more?
   d) To present, if possible, information in immediately usable form; the operator is not required to make mental conversions of the indicated values?

11) Is the use of multiple pointers on a single pivot avoided where possible?

12) Is one pointer plus an adjacent counter used where scale expansion is necessary?

13) Are combinations of single-value indicators or composite pictorial representations used for multi-dimensional information where possible?

14) Are figures oriented vertically on dials which have a fixed scale and moving pointer?

15) When the scale is of finite length, is there a scale break between the end and beginning of the scale equal to at least a major scale division?

16) Are figures oriented radially on dials which have a fixed pointer and moving scale? Where possible, is the index oriented at the 12-o'clock position?

17) Where figures of a dial move past an open window, are they oriented so that they appear vertically at the open window? Do two or more figures appear in the window simultaneously?

18) Do numbers appear to increase in a clockwise direction, left to right, or bottom to top?

19) When two or more similar scales appear on the same panel, do they have compatible numerical progression and scale organization?

20) Are pointers and scale indices oriented so that the pointer, either moving or fixed, is close to the index and yet does not cover the number?

21) Are pointers:

   a) Designed so that there is a minimum distance between tip and scale index - 1/16 inch maximum?
   b) Mounted so that visual parallax is minimized?
   c) Painted the same color as numbers and indices when possible?

d) Designed so that when reciprocal readings are necessary, the two ends of the pointer are readily identifiable?
e) Possessed of simplicity of pointer-tip design for reading speed and accuracy?

22) Are counters designed so that:

a) The numbers "snap" into place to eliminate blurring?
b) An upward movement of the counter drum indicates a numerical increase?
c) Large horizontal spacing between number drums is avoided?
d) Last digits which have little value, as in large values of range or altitude, are replaced with stationary zeros and drum spaces are blanked out completely during the time when no numerical value is to appear?
e) Counters are mounted as close to the panel surface as possible to provide maximum viewing angle and minimum shadow effects from ambient lighting?
f) Counters are oriented so that they may be read from left to right?

23) Are master warning, master caution, and summation lights used to indicate the condition of an entire subsystem set apart from lights which show the status of the subsystem components?
24) When an indicator is associated with a control, is the indicator light located so as to be immediately and unambiguously associated with the control?
25) Are indicators for critical functions located within 30 degrees of the operator's normal line of sight?
26) Are warning lights an integral part of, or located adjacent to, the lever, switch, or other control device by which the operator is to take action?
27) Is the brightness of indicators at least 10 percent greater than the surrounding brightness?
28) If display panels are to be used outdoors, have provisions been made to prevent reflected sunlight from making indicators appear illuminated when they are not, or to appear extinguished when they are illuminated?
29) Is brightness contrast between indicators and the immediate panel background at least 50 percent?
30) Are the brightness levels of warning and caution indicators from 3 to 5 times the brightness of other indicators on the same panel?
31) Are legend indicator lights used instead of simple indicator lights, where possible?
32) Are indicator lights color coded as follows:

a) RED - Malfunction; error; no-go; failure; stop action; etc.?

b) FLASHING RED - Emergency; personnel or equipment disaster?
c) AMBER - Marginal condition; impending danger; caution; etc.?
d) GREEN - In tolerance; acceptable; ready; go ahead, etc.?
e) WHITE - Conditions which have no right or wrong implications, e.g., functional or physical condition; action in progress; etc.?

6.2.3 Auditory Warning Devices

a. Energize the equipment under test and operate under conditions of normal expected use.

b. Record measurements taken and detailed answers to the following questions based on the cumulative experience and observations of test personnel gathered over the entire period of the commodity test:

1) When extremely critical functions are indicated by means of an audio signal, is a flashing red light also provided to indicate the type of malfunction and, where feasible, the corrective action required?
2) Where appropriate, do the audio signals "explain" the responses to be executed so that compatibility is optimized (e.g., is a pure tone signal to "lift up" a tone of increasing pitch rather than a tone of decreasing pitch)?
3) Is the major concentration of energy in audio warning signals between 250 and 2500 cps?
4) Is the intensity and direction of aural alarms and signals compatible with the acoustical environment of the intended receiver, and with the requirements of other personnel in the area?
5) Is the sound pressure level of audio signals at least 10 decibels above the maximum anticipated ambient noise level?
6) Are audio warning signals used in occupied areas where the ambient noise level exceeds 100 decibels?
7) Where signals of high sound pressure levels are required, are the signals of short duration and relatively low frequencies within the authorized spectrum?
8) Are audio warning signals of such intensity as to cause discomfort or "ringing" in the ears as an after-effect?
9) Where audibility is a critical factor, is a relatively high sound pressure level used with the signal energy being concentrated in the frequency in which the background noise is lowest?
10) When several different auditory signals are used to alert an operator to different types of conditions, are discriminable differences in pitch, intensity, beat, harmonics, etc. used?
11) Where discrimination of warning signals is critical to personnel safety or system performance, are audio signals coded to correspond with different conditions requiring critically different operator responses (e.g., emergency, security, maintenance, safety hazards, etc.) used?

12) Are aural alarms readily differentiated from routine signals such as telephone bells, buzzers, and normal operational noises?
13) Do audio signals interfere with other critical functions or mask other critical auditory signals with which they may happen to coincide?
14) Does the input signal to the operator avoid providing more information than is necessary to carry out the proper response (e.g., instructions signaled to one position in a system need not be signaled to other positions if the positions are autonomous)?
15) Does the same signal designate the same information at all times?
16) Where feasible, are interrupted or variable signals rather than steady-state signals used to minimize perceptual adaption?

6.2.4 Controls

a. Energize the equipment under test and operate under conditions of normal expected use.

b. Record measurements taken and detailed answers to the following questions based on the cumulative experience and observations of test personnel gathered over the entire period of the commodity test:

1) Are discrete-adjustment type (detent) controls used when performance requirements are such that the controlled object can be adjusted in a limited number of discrete steps? (See Figure 6.)
2) Are continuous adjustment type controls used when precise adjustments are needed along a continuum, or when a large number of settings (usually more than 24) is required? (See Figure 6.)
3) Are multi-rotational type controls used when high precision is required over a wide range of adjustments? (See Figure 6.)
4) When force and range of settings are the primary considerations, are controls such as are shown in Table II used?
5) Are controls oriented to fit normal habit-pattern reflexes; e.g., does a clockwise movement of the control produce a clockwise motion to its visual display?
6) Are controls shape coded, where possible, to improve visual and tactile identification, by the use of standardized shapes and, when feasible, functional shapes which suggest the purpose of the control?
7) Are class A knobs used for twirling or spinning (more than one full turn is required) for which knob position is not important?
8) Are class B knobs used when less than one full turn is required and knob position is important?

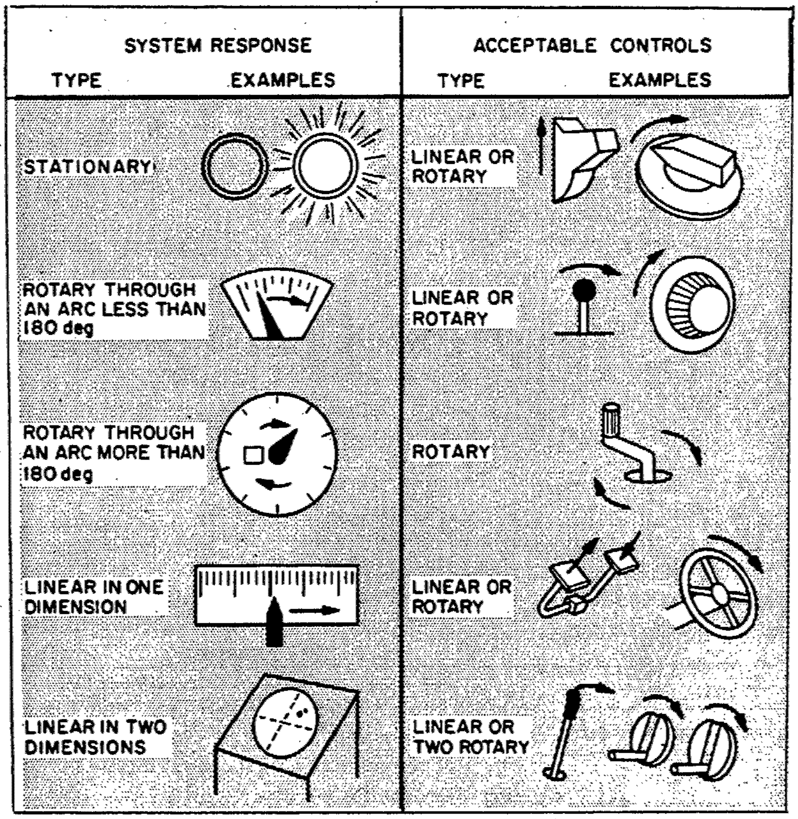


Figure-6 Acceptable Controls for Various Types of System Responses

For SMALL forces and . . .	*Use . . .*
Two discrete settings	Hand pushbutton, foot pushbutton, or toggle switch
Three discrete settings	Toggle switch or rotary selector switch
Four to 24 discrete settings	Rotary selector switch
Small range of continuous settings	Knob or lever
Large range of continuous settings	Crank
For LARGE forces and . . .	*Use . . .*
Two discrete settings	Detent lever, large hand pushbutton, or foot pushbutton
Three to 24 discrete settings	Detent lever
Small range of continuous settings	Handwheel, rotary pedal, or lever
Large range of continuous settings	Large crank

Table II. Recommended Controls for the Case Where Both Force and Range of Settings are Important

9) Are controls size coded where possible, with the largest knob always about 20 percent larger than the smaller one for knobs ranging from ½ to 6 inches in diameter?
10) If controls are color coded, are the colors limited to black, grey, red, green, amber (yellow), white, and blue, and the color coding compatible with that of the visual display?
11) If controls are location or position coded, are they in the same relative position from panel to panel, permitting the operator to establish a habit pattern?
12) When mode-of-operation control coding is used, is the operator able to sense the direction of movement, amount of displacement, or the type and amount of resistance?
13) Are controls designed and located so that they are not susceptible to being moved accidentally?
14) Are rotary switches provided with detents at each position (setting)?
15) Is elastic resistance that builds up and then decreases as each position (detent) is approached used with rotary switches so that the control will fall into each detent and cannot stop easily between adjacent detents?
16) Are the moving pointers of rotary switches bar-type knobs with tapered tips rather than round knobs?
17) In cases of extreme necessity where rotary switches have more than 24 positions, is the minimum separation between adjacent positions 1/4 inch as measured at the index marks.
18) Are control positions of rotary switches less than 180 degrees from each other to aid in reducing errors in setting and reading the wrong end of the pointer? (See Figure 7).

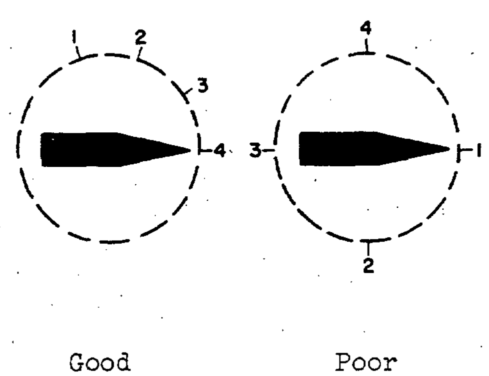


Figure 7. Control Position Separation

19) Are steps provided at the beginning and end of the range of control switches of rotary switches to facilitate

blind-positioning by the operator?

20) Is elastic resistance (aided by sliding friction if necessary) that starts low and builds up rapidly with a sudden drop used with pushbuttons to provide an indication that the control has been activated?
21) Are the tops of pushbuttons concave to fit the fingers, or if this is impractical, is a rough surface provided to prevent slipping?
22) Is a positive indication of control activation (e.g., audible click, snap feel, or integral light) provided with push-buttons?
23) Is the use of foot-operated pushbuttons limited to non-critical operations such as press-to-talk switches?
24) Are foot pushbuttons provided with elastic resistance aided by static friction to support the foot? Does the resistance start low, build up rapidly, then drop suddenly to indicate the control has been activated?
25) Are foot-operated controls designed to be operated by toe (ball of the foot), rather than by the heel and provided with a positive indication of control activation (e.g., snap feel or audible click)?
26) Where space permits, are foot pedals hinged at the heel used instead of foot pushbuttons to aid in locating and activating the control?
27) Is elastic resistance (used in such a way that it builds up and then decreases as the desired position is approached) so that the control will snap into position and not stop between adjacent positions used with toggle switches?
28) Are toggle switches mounted so that the "on" position is always forward, up, or to the right as the operator looks at the switch?
29) Do toggle switches provide a visual cue as to the switch position, i.e., at least 30 degrees either side of center position?
30) Are small round knobs (approximately 1 inch in diameter) used for non-critical adjustments, such as volume, focus, and dimmers, and larger knobs (approximately 2 inches in diameter) for more critical adjustments such as tuning or frequency selection?
31) When bracketing is used for locating a visual or auditory null position (e.g., tuning a transmitter), does the knob move through an arc of 30-60 degrees on either side of the null position so as to allow a misalignment to be just noticeable?
32) When two or more knobs are ganged on a concentric shaft arrangement, is the largest control used for vernier adjustment?
33) Are knobs which are less than 3/4 inch in depth knurled rather than serrated? Do serrated knobs have point contacts rather than rounded ones and evenly spaced serration rather than uneven or widely spaced ones?

34) Are cranks, rather than knobs or handwheels, used for tasks involving at least two rotations of control movement?
35) For tasks involving large slewing movements plus small fine adjustments, is a crank handle mounted on a knob or handwheel?
36) Are handles for cranks approximately $1\frac{1}{2}$ inches in length by $\frac{1}{2}$ inch in diameter for operations requiring fast wrist and finger movements; 3-3/4 inches in length by 1 inch in diameter for operations requiring arm movement by heavy loads?
37) Is the diameter of high-speed cranks approximately $4\frac{1}{2}$ inches?
38) Is the control ratio for each type of movement of lever-type (joystick) controls adjustable by either electrical or mechanical means so as to provide smooth fine adjustive movements?
39) Is the direction of joystick movement compatible with display movement, as in other types of controls?
40) Are lever-type controls mounted so as to provide support for the body part being used; elbow support for large hand movements, forearm support for small hand movements, and wrist support for finger movements?
41) Is the joystick movement equally free in all directions?

6.2.5 Labeling

a. Energize the equipment under test and operate in the normal usage mode.

b. Carefully check all assemblies, components, parts, controls, displays, test points, and items of equipment that must be located, identified, read, or manipulated for the presence of appropriate labels.

c. Record measurements taken and detailed answers to the following questions based on the cumulative experience and observations of test personnel gathered over the entire period of the commodity test:

1) Are permanent means of labeling such as etching, embossing, or engraving used rather than printed stamped, or stencilled labels placed on the surface of the equipment?
2) Are labels placed on or very near the items which they identify?
3) Do the labels obscure any other information needed by the operator (e.g., displays)? Are the labels obscured by other units in the equipment assembly?
4) Are labels located in a consistent manner throughout the equipment and system?
5) Are labels located such that they are read horizontally from left to right with vertical orientation used only when labels are not critical for safety or performance, and where space is severely limited?
6) Do labels describe primarily the function of equipment items,

and only secondarily their engineering characteristics or nomenclature?

7) When the general function is obvious, do labels identify only the specific function (e.g., frequency as opposed to frequency selector)?
8) Are labels as concise as possible without distorting the intended meaning with the choice of words based on operator familiarity where possible?
9) Do labels use common technical terms for particular populations(e.g., maintenance technicians) even though they may be unfamiliar to other populations?
10) Are abstract symbols used on labels only when they have a commonly accepted meaning to all intended readers, and common, meaningful symbols (e.g. %, +, -) used where necessary?
11) Are standard abbreviations used on labels only where necessary to reduce the amount of space required or to improve intelligibility?
12) Where ambient illumination is above one foot-candle, do labels use black characters on a white background?
13) Where ambient illumination is below one foot-candle or where night vision is required, do labels use either white, phosphorescent, or backlighted characters on a dark background?
14) Do labels use block type characters, without serifs or flourishes, and with readily apparent openings and breaks? (See Figure 8 for letters and Figure 9 for numerals.)
15) Are capital letters used for labels with upper-and-lower-case letters used for extended instructional material, where required?
16) Are labels designed with a width-to-height ratio for normal characters of about 3 to 5, minimum space between characters of one stroke width, and minimum space between words of one character width?
17) Is maximum simplicity commensurate with informational requirements maintained in all labeling?
18) Is the stroke width of black characters on white background about one-sixth of the character height, and the stroke width of white figures on black background kept to about one-seventh to one-eighth of the character height to avoid spreading or irradiation of the light figure?

6.2.6 Workspace Design and Layout

a. Energize the equipment under test and operate under conditions of normal expected usage.

b. Carefully observe and measure the workspace design and layout to determine degree of conformance with applicable human factors criteria for accommodating the intended user.

c. Record detailed answers to the following questions based on the

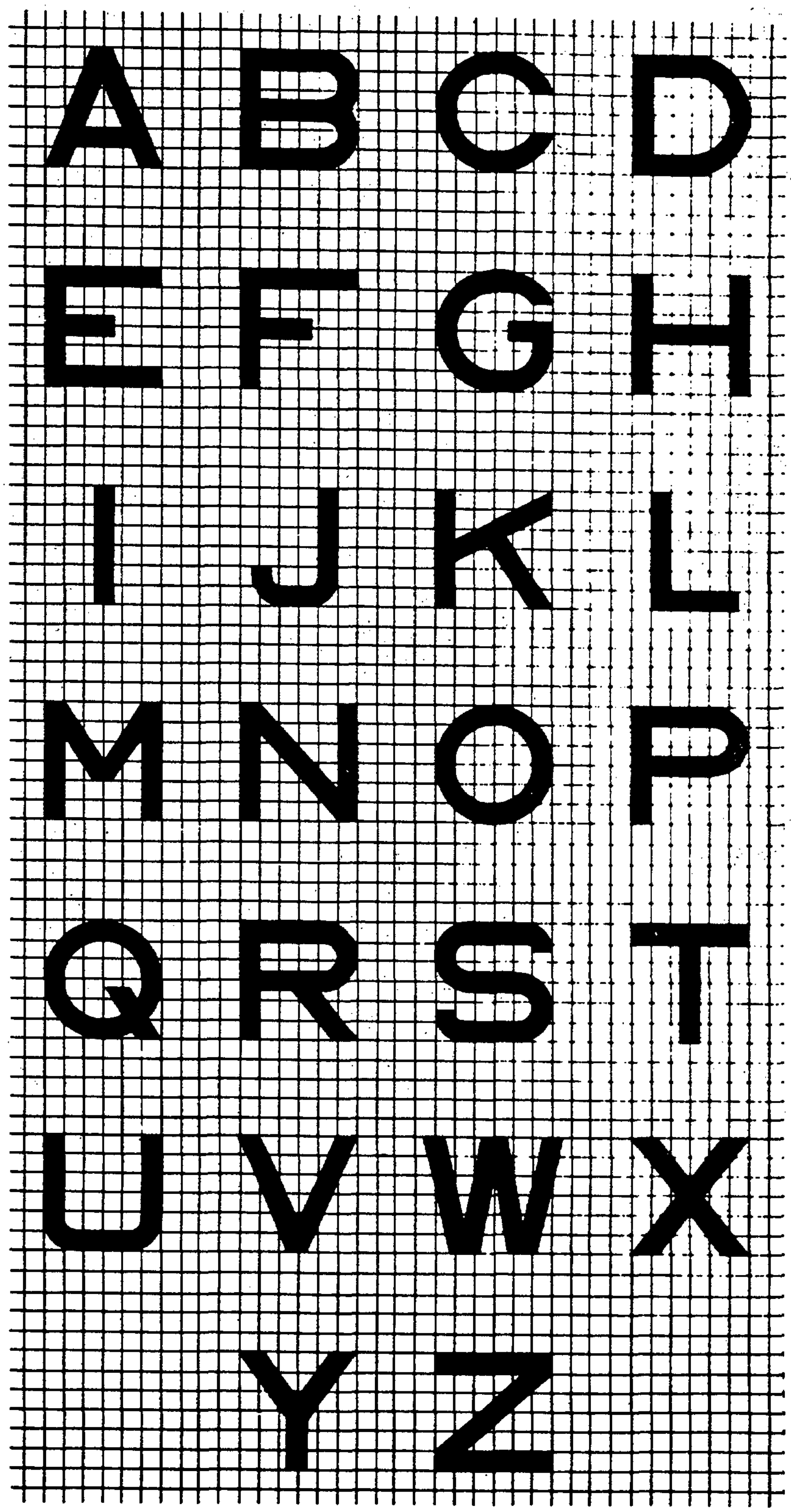


Figure-8. Style of Letters for Equipment Labels

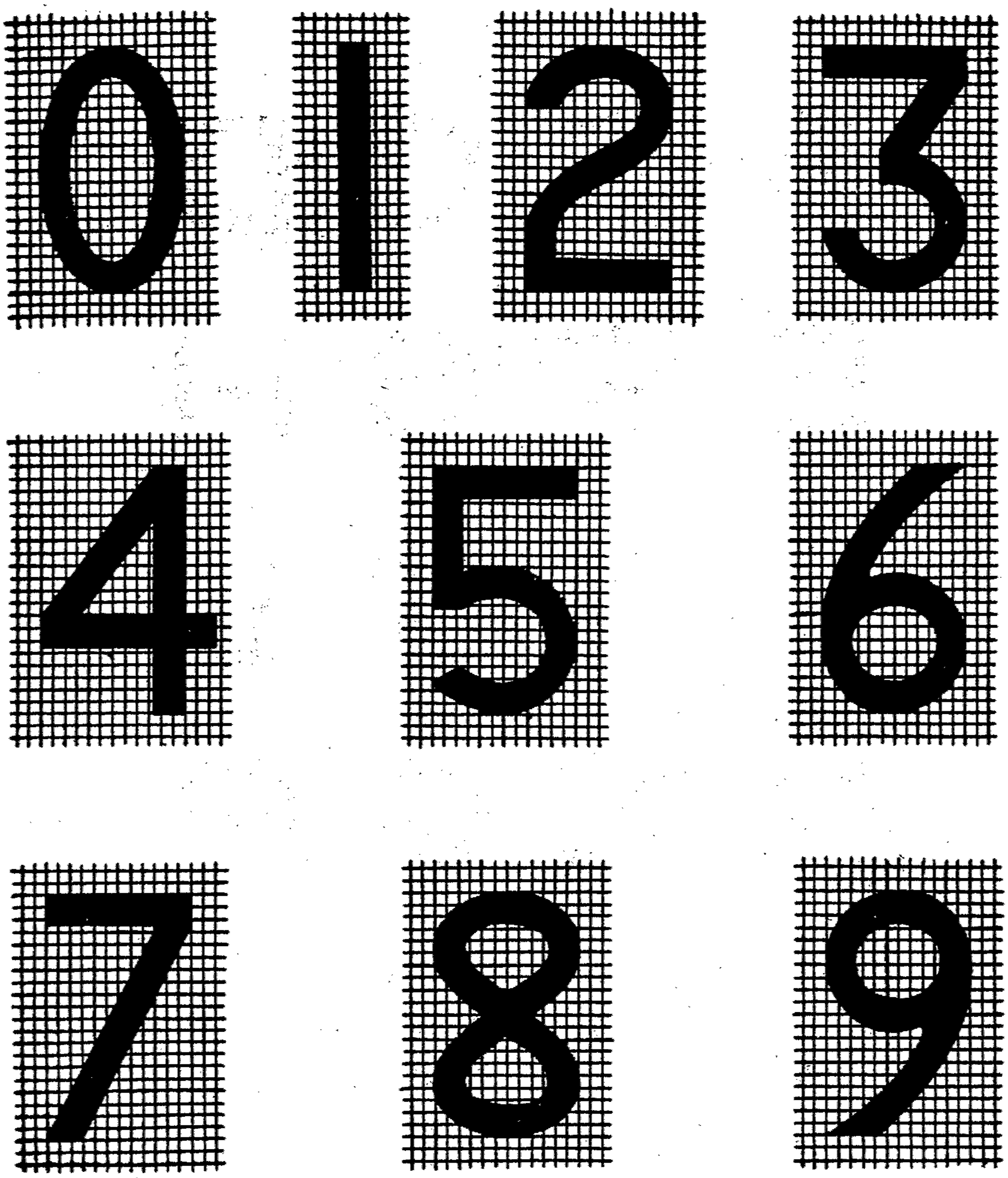


Figure-9. Style of Numerals for Equipment Labels

cumulative experience and observations of test personnel gathered over the entire period of the commodity test:

1) Is the location, size, configuration and accessibility of equipment such that it is operable and maintainable by at least the 5th through the 95th percentile group of the user population?
2) Are cabinets, consoles, and work surfaces that require an operator to stand or sit close to their front surfaces provided with a kick space at the base at least 4 inches high?
3) Are handles on cabinets and consoles recessed whenever practicable, to eliminate projections on the surface?
4) Whenever feasible, is approximately 4 to 5 feet of free floor space provided in front of each console; at least 3½ feet for equipment racks that require maintenance?
5) Is suitable space provided on consoles and workspace for the storage of manuals, worksheets, and other materials that will be used at the work position?
6) Are visual displays mounted on vertical panels and used in normal equipment operations by standing operators, located in an area between 40 inches and 72 inches above the standing surface?
7) Are indicators which must be read precisely and frequently by standing operators located in an area between 50 inches and 69 inches above the standing surface?
8) Are controls which are mounted on a vertical surface and used by standing operators in normal equipment operations located in an area 34 inches and 73 inches above the standing surface?
9) Are controls which require precise and frequent operation by standing operators located in an area between 34 inches and 57 inches above the standing surface?
10) Are work benches and work surfaces used to support jobs, instruction manuals and worksheets provided for standing operators with work surfaces approximately 36 inches above the floor?
11) Are writing surfaces, if required on equipment consoles, at least 16 inches deep?
12) Are desk tops and writing tables at least 30 inches above the floor?
13) Are chairs intended to be used at consoles operationally compatible with the console configuration?
14) Are chairs provided with:

    a) Vertical seat adjustment of at least 4 inches?
    b) Supporting back rest that reclines between 103 and 115 degrees?
    c) Backrest and seat cushioning with at least 1 inch of compression?

d) Armrests, unless otherwise specified?

15) Do chair backrests engage the lumbar and thoriac regions of the back, and support the torso in such a position that the operator's eyes can be brought to the "eye line" with no more than 3 inches of forward body movement?
16) Are armrests that are integral with the operator's chair at least 2 inches wide and 8 inches long?
17) Are retractable armrests provided with chairs, when necessary, to maintain compatibility with an associated console?
18) Are visual displays that are mounted on vertical panels and used in normal equipment operation located in an area between 8 and 44 inches above the mid-point of the sitting surface?
19) Are indicators that must be read precisely and frequently located in an area between 16 and 35 inches above the sitting surface?
20) For consoles requiring horizontal vision over the top, are critical visual warning displays located at least 22½ inches above the mid-point of the sitting surface?
21) Are controls that are mounted on a vertical surface and used in normal equipment operation located in an area between 8 and 35 inches above the mid-point of the sitting surface?
22) Are controls requiring precise or frequent operation located between 8 and 30 inches above the mid-point of the sitting surface?
23) Is the workspace clearance for work to be accomplished in squatting, kneeling or crawling positions at least:

a) Squatting workspace, minimum values - height, 48 inches; width, 27 inches?
b) Kneeling workspace, minimum values - height, 56 inches; width, 42 inches?
c) Kneeling crawl space, minimum values - height, 31 inches; length, 59 inches?
d) Prone work or crawl space, minimum values - height, 17 inches; length, 96 inches?

24) Are ladders used when the desired rise from the horizontal is 75 degrees to 90 degrees and stairways used when the desired rise from horizontal is 50 degrees or less?
25) Are stair ladders of metal construction provided for slopes between 50 to 75 degrees?
26) Do stair ladders possess the following characteristics:

a) Tread depth of 6½ inches for a 50 degree rise; 3 to 4 inches for a 75 degree rise?
b) Tread rise of 8½ inches for a 50 degree rise; 10½

inches for a 75 degree rise, with all tread rises open at the rear?

c) Handrail diameter from 1 1/4 to 1 3/8 inches; handrail separation, from 21 to 24 inches?
d) Tread surface on exterior stair ladders constructed of open grating material or treated with non-skid material?
e) Landings provided every tenth or twelfth tread?

27) Do vertical ladders possess the following characteristics:

a) Rise between rungs - uniform and from 11 to 12 inches; where this is impractical due to the small number of rungs required, a uniform rise of not less than 10 nor more than 14 inches?
b) Distance between top rung and landing approximately 6 inches; never less than 2½ inches nor more than 12 inches?
c) Distance between rungs and supporting wall or obstruction - minimum of 8 inches?
d) Horizontal distance between strings (ladder width) - 18 to 21 inches, never less than 12 inches?
e) Ladder strings (vertical supports to which rungs are fastened) - extending above the top floor level to a height of 3½ feet, where possible?
f) Construction - metal, with rungs coated with non-skid material?

28) Do exterior personnel platforms and work areas possess the following characteristics:

a) Surfaces of exterior platforms and work areas constructed of open metal grating; surfaces of interior walkways and exterior personnel platforms for which open grating is impractical, treated with non-skid material?
b) All open sides of personnel platforms, 5 feet in height or more above the adjoining surface, protected by guard rails (with intermediate rails) and a toeboard or guard screen?
c) Guardrail overall height, 42 inches; toeboard or guard screen minimum height, 3 inches?
d) Handrails furnished where needed?

6.2.7 Operator Comfort and Lack of Interference

a. Throughout the normal course of the commodity test, and during any period devoted primarily to human factors testing, ensure that all test personnel observe the equipment during operational conditions with respect not only to the man-machine interface but from an operator comfort and lack of interference standpoint.

b. Record opinions and comments resulting from these observations as they occur spontaneously during the equipment operation and by application of the following techniques:

1) Interview
2) Questionnaire
3) Use of human error forms (Appendix A)
4) Use of error likely forms (Appendix A)

c. Record narrative comments obtained from all test personnel through daily observation, interview and questionnaire concerning the following:

1) The nature of the task performed.
2) Difficulties experienced by the operator.
3) The operator's reaction to or evaluation of the equipment he has been using.
4) Details of incidents or problem situations in which operators are participants or observers.
5) The operator's evaluation of his performance adequacy or that of his co-worker's or subordinates.

6.2.8 Special Observational Tests

a. Conduct an operational test of the equipment or system, under the guidance of a human factors engineer, utilizing a human factors specialist crew, if applicable.

b. Perform time and motion studies; if applicable, coordinating the test performance with a human factors engineer, and utilizing activity sampling techniques for the study of work units and operator activities, including time spent in various activities and sequence of performance.

c. Record test data during Steps (a) and (b) above, as determined by the test officer and human factors engineer, according to the nature of the tests or human factors problem areas.

6.3 TEST DATA

6.3.1 Preparation for Test

Data to be recorded prior to testing shall include but not be limited to:

a. Nomenclature, serial numbers(s), manufacturer's name, and function of the item(s) under test.

b. Nomenclature, serial number, accuracy tolerances, calibration requirements, and last date calibrated of the test equipment selected for the tests.

c. Damages to the test item incurred during transit and/or manufacturing defects.

6.3.2 Test Conduct

Data to be recorded in addition to specific instructions listed below for each subtest shall include:

a. An engineering logbook containing in chronological order, pertinent remarks and observations which would aid in a subsequent analysis of the test data. This information may consist of temperature, humidity, long and fatiguing watches, etc. and other appropriate environmental data, or other description of equipment and component operations or functions or deficiencies.

b. Test item sample size (number of measurement repetitions).

c. Instrument or measurement system mean error stated accuracy.

6.3.2.1 Control-Display Relationships

Data to be recorded for the Control-Display Relationships subtest shall consist of measurements taken and answers to the questions contained in paragraph 6.2.1.

6.3.2.2 Visual Displays

Data to be recorded for the Visual Displays subtest shall consist of measurements taken and answers to the questions contained in paragraph 6.2.2.

6.3.2.3 Auditory Warning Devices

Data to be recorded for the Auditory Warning Devices subtest shall consist of measurements taken and answers to the questions contained in paragraph 6.2.3.

6.3.2.4 Controls

Data to be recorded for the Controls subtest shall consist of measurements taken and answers to the questions contained in paragraph 6.2.4.

6.3.2.5 Labeling

Data to be recorded for the Labeling subtest shall consist of measurements taken and answers to the questions contained in paragraph 6.2.5.

6.3.2.6 Workspace Design and Layout

Data to be recorded for the Workspace Design and Layout subtest shall consist of measurements taken and answers to the questions contained in paragraph 6.2.6.

6.3.2.7 Operator Comfort and Lack of Interference

Data to be recorded for the Operator Comfort and Lack of Interference subtest shall consist of:

a. Logbook or data from observations and opinions of operators and test personnel as they occur during the course of the test.

b. Data from interviews, in the form of interviewer's notes, stenographer's notes, or tape recordings.

c. Completed questionnaires.

d. Completed human error forms and error-likely forms.

6.2.3.8 Special Observational Tests

Data to be recorded for the Special Observational Tests subtest shall be determined by the test officer and human factors engineer, according to the nature of the tests.

6.4 DATA REDUCTION AND PRESENTATION

All test data shall be properly marked for identification and correlation and grouped according to subtest title. Test criteria or test item specifications shall be noted on the test data presentation to facilitate comparison. Where necessary, test data measurements shall be converted to be compatible with units given by test criteria or specifications.

Specific instructions for the reduction and presentation of individual subtest data are outlined in the succeeding paragraphs.

6.4.1 Control-Display Relationships

a. Data obtained from this test shall be examined for items of apparent significance. This information shall be extracted, collated, and presented along with any supporting photographs and sketches, for final evaluation.

b. A summary of results and conclusions derived from the test shall be presented.

6.4.2 Visual Displays

a. Data obtained from this test shall be examined for items of apparent significance. This information shall be extracted, collated, and presented along with supporting photographs and sketches, final evaluation.

b. A summary of results and conclusions derived from the test shall be presented.

6.4.3 Auditory Warning Devices

a. Data obtained from this test shall be examined for items of apparent significance. This information shall be extracted, collated, and presented along with supporting photographs and sketches, for final evaluation.

b. A summary of results and conclusions derived from the test shall be presented.

6.4.4 Controls

a. Data obtained from this test shall be examined for items of apparent significance. This information shall be extracted, collated, and presented along with supporting photographs and sketches, for final evaluation.

b. A summary of results and conclusions derived from the test shall be presented.

6.4.5 Labeling

a. Data obtained from this test shall be examined for items of apparent significance. This information shall be extracted, collated, and presented along with supporting photographs and sketches, for final evaluation.

b. A summary of results and conclusions derived from the test shall be presented.

6.4.6 Workspace Design and Layout

a. Data obtained from this test shall be examined for items of apparent significance. This information shall be extracted, collated, and presented along with supporting photographs and sketches, for final evaluation.

b. A summary of results and conclusions derived from the test shall be presented.

6.4.7 Operator Comfort and Lack of Interference

a. Log books, data forms, records of interviews, and completed questionnaires, human error forms and error-likely forms shall be examined for items of apparent significance and these shall be presented in summary form.

b. Supporting photographs and sketches shall also be presented for final evaluation as required.

6.4.8 Special Observational Tests

Data reduction and presentation shall be determined by the test officer and the human factors engineer.

APPENDIX A

HUMAN FACTORS ENGINEERING

1. GENERAL

1.1 HUMAN FACTORS EVALUATION

A comprehensive and thorough human factors evaluation of complex systems requires the design of special tests for each system and equipment item by a skilled human factors engineer.

When such support is not available, it is necessary to use basic methods of evaluation such as: (1) observation and measurement, (2) interview and questionnaire, (3) checklists for general guidance, and (4) comparative tests made under controlled conditions of environmental stress and task interference. When properly applied, these methods will provide significant objective data for evaluation of equipment design as well as observational data useful for limited evaluation of equipment dynamics and man-machine relationships.

In performing human factors engineering tests, objective measurements which can be recorded in quantitative terms are preferred to subjective opinions, comments, and ratings.

Since the basic methods of observation and interview have been neither standardized nor quantified, they contain a large measure of subjectivity. However, there is nothing inherently "improper" about these methods since they do produce valid and valuable information when evaluated properly. Also, for much performance evaluation, no better methods are available.

Objective measurements can be made with respect to those preferred features of hardware design, such as dimensions, type, and size of displays, controls, labeling, accessibility for maintenance, and safety which have been generally accepted in the literature as best meeting the human requirements. Many of these preferred requirements are contained in existing military standards and specifications. In addition, features which have been found to meet a stated requirement must often be further assessed to determine suitability with respect to all other associated requirements.

Considerable research has been done in an effort to quantify the performance of the human element in the man-machine relationship and develop a numerical measure of operability. Although the results of these studies are promising, no practical methodology for conducting such tests exists at this time, except as designed by a human factors engineer for each specific application. Until widely applicable quantitative standards and methodologies are developed, the services of a human factors specialist will be required for evaluating those areas of concern which do not lend themselves to reasonably objective measurements through use of basic observational techniques.

1.2 SYSTEM AND TASK ANALYSIS

Before any evaluation of the human factors in a test item can be undertaken, it is necessary to learn as much as possible about what people will have to do with the equipment in an operational situation in the field. This requires a system and task analysis for systematically defining the equipment, personnel, facilities, and procedures required to accomplish the mission. The analysis should be done to the level of detail necessary for determining the human factors objective and developing the test and evaluation techniques. The analysis may include the following overlapping steps:

a. Preparation of functional flow block diagrams to depict the sequence and interaction of operations and control functions.

b. Analysis of each flow block to determine:

1) Detailed functions
2) Time and accuracy requirements for performance of functions
3) The consequences if these requirements are not met

c. Preparation of a description of man-equipment inter-actions brought about by an operator accomplishing a unit of work (showing the sequential manual and intellectual activities of the operator).

1.3 METHODS OF DIRECT OBSERVATION

The most direct way of evaluating problems in human engineering is to observe the equipment and the human operators in an actual working situation. Although the observational method is not the complete answer in all situations, it is used in some form and to some degree, alone or in combination with other methods, in every evaluation. The most commonly used methods and techniques of direct observation are listed below:

a. Operator Opinions - obtained by interviews and questionnaires.

b. Activity Sampling Techniques - timing of operator activity and the discrete steps required for completion of a work unit, e.g., activities and steps in handling a message from originator to delivery to addressee.

c. Process Analysis - a group of techniques for recording compactly the various steps involved in a process, and employing process charts, flow diagrams and link analysis.

d. Records - records of tests previously made on the equipment; equipment failure and maintenance records.

1.4 AIDS FOR DATA COLLECTION

The timely and accurate recording of test data is enhanced by:

a. Detailed data forms prepared in advance of the test and tailored to each specific subtest.

b. Checklist as convenient reminders and aids for checking equipment design features against criteria.

c. Carefully prepared questionnaire for obtaining operator opinion.

d. Human Error Report Forms (Figure A-1) for recording and analyzing operating errors as they occur.

e. Error-Likely Report Forms (Figure A-2) for reporting of operating or equipment conditions which appear to operators as likely to cause errors.

1.5 CONDITIONS FOR TESTING

During the course of the commodity test, human factors which cannot be measured quantitatively (e.g., operability), should be evaluated during those periods and under operational conditions most closely resembling conditions expected to be encountered by the system in actual use. The conditions outlined in the paragraphs which follow should be observed.

a. <u>Mission</u>

Require the system to carry out those missions, and only those missions, for which the system is intended or to which the system is likely to be assigned.

b. <u>Tasks</u>

The tasks to be performed should be a fair sample of those to be performed when the system is in actual use, and should be comparable in speed, number, and difficulty to those with which the system must cope in the future. The following steps should be taken to fulfill this requirement:

1) Require operators to work at realistic speeds. Demonstrations that permit operators to work at their own pace can make a system appear to be more accurate and to work more smoothly than it will work in actual service.

2) Give operators the same amount and kind of work that they will have in future operational situations. Systems that perform well at light or moderate loads may break down when higher loads are imposed.

3) Make all aspects of task difficulty realistic; the problems should not be too easy, nor should they be problems to which the operators already know the answers.

4) Require operators to observe all the rules of realistic operation; even if some of the rules are not directly pertinent to the evaluation, they are necessary to duplicate the effects of the task on the performance of the system.

HUMAN ERROR REPORT FORM

Name of Test ____

1. Name of task or subtest (if any) ______________________________

   Title of identifying number of written procedures __________________

   Page and paragraph number(s) in written procedures __________________

2. Tell exactly what equipment was involved. Be complete and specific, that is, give component (or part) and the tools or test equipment involved. (Use extra sheet of paper if needed for this or other items below.)

3. Tell exactly what the person making the error was supposed to do or what the task required.

4. What did he do, or fail to do, which was in error? Describe the error.

   Note: As a check on how well you have completed the above 4 items, given your description of the error, and if he wanted to, could someone else familiar with the equipment make the error you have described?

5. Did time-pressure, weather, hazards, or other test conditions contribute to the error? How?

6. What had to be done (or what should have been done) to correct the error?

7. What were the consequences of the error?

8. What do you think would be the likely consequences of this error in the operational situation?

9. Do you think this error would be less, about the same, or more likely in the operational situation? Why?

10. What suggestions do you have to correct the above situation? Your suggestions might involve changing the equipment, the procedures, the MOS, or the training given beyond the MOS.

    Name and Rank ______________________________

    Date ______________________________

Figure A-1. Human Error Report Form

ERROR-LIKELY FORM

Name of Test ____________________

1. Name of task or subtest (if any) ____________________

   Title or identifying number of written procedures ____________________

   Page and paragraph number(s) in written procedures ____________________

2. Tell exactly what equipment is involved. Be complete and specific, that is, give component (or part) and the tools or test equipment involved. (Use extra sheet of paper if needed for this or other items below).

3. Tell exactly what the person is expected to do or what the task requires.

4. Tell why this is an error-likely situation. That is, tell exactly where or how an error is likely to be made. Try to keep in mind the potential operational situations, that is, the weather, possible enemy action, time-pressures, hazards, and so on. (If you have seen anyone almost make this error, tell what he did.)

5. Could the error be corrected if made. If so, how?

6. What would be the likely consequences of the error in the operational situations?

(Note: As a check on how well you have completed the above 6 items, given your description of the error, and if he wanted to, could someone else familiar with the equipment make the possible error you have described?)

7. What suggestions do you have to correct the above situation? Your suggestions might involve changing the equipment, the procedures, the MOS, or the training given beyond the MOS.

Name and Rank ____________________

Date ____________________

Figure A-2. Error-Likely Form

c. Environment

Make the physical and environmental conditions duplicate those to be found in the future use of the system. If extreme conditions of heat, cold, humidity, cramping of the body, long and fatiguing watches, etc., are to be encountered in operational use, these should be included in the conditions of the system evaluation. These conditions should produce, for the operators, the same tasks, stresses, motivation, and knowledge of results to which they will be subjected under operating conditions.

d. Operating Personnel

Make certain that the operators used in the evaluation represent those who will be operating the equipment in actual use, particularly with respect to such characteristics as age, general ability, experience, and training. The following guides will be useful in accomplishing this objective:

1) Avoid the use of biased subjects - those that may have some stake in the outcome of the evaluation. A person who wants one system to be better than another, or expects it to be, is prejudiced. No matter how much he tries to be fair, his prejudices influence his performance and his judgment.

2) Do not use "expert" equipment operator personnel as test operators, except as required to determine non-human performance factors. Personnel who are unusually experienced often tend to prefer the familiar and distrust the new and different. They may suffer from habit interference; having developed one set of habits with conventional systems makes it more difficult for them to use a new system effectively.

3) Motivate the operators to the same extent they are likely to be motivated in the future use of the system. If they feel they are just doing "exercises" they are likely to perform considerably below par. One way of obtaining realistic motivation is to provide quick and correct knowledge of results to the operators. They should have the same kind of feedback from their activities as they would have in operational situations.

4) The following general rules for the training of operators should be observed:

(a) Give operators adequate instruction in the tasks to be performed.
(b) Provide an objective measure of training by scoring and recording their performance.
(c) Continue training until further improvement is negligible.

(d) When two systems are being compared, make certain that the personnel operating the two systems have comparable training in handling their respective tasks.

e. Counterbalancing

Both machine and men, but particularly men, are likely to vary in their performance over a period of time. To minimize the influence of this variability on the outcome of an evaluation, that is, to prevent it from unfairly biasing the results, the conditions of testing should be counterbalanced in every way that might possibly bias the results. To do so the evaluator should observe the following:

1) If possible, make a comparison of systems at exactly the same time. If this is not possible, then switch back and forth between systems in a predetermined counterbalanced order. In planning a counterbalanced order, avoid simple alteration because this might introduce a bias. Instead use an "ABBA" order, where "A" is one system and "B" is another.

2) Where possible, use the same men and the same machines in the evaluation of different systems. This minimizes the possibility that differences in outcome can be attributed to irrelevant differences among people and equipment. If systems are simultaneously compared, or if for some reason more than one crew is required, evaluations should be repeated, switching crew "A" to system "B".

3) Some systems, of course, are different because they are made up of two different equipments that impose different tasks on operators. In this case, beware of habit interference which might be involved whenever two equipments or tasks require different habits or skills. If habit interference might be a factor then it is better not to switch operators. Instead, operators of comparable skill in their respective tasks should be selected and kept on their respective equipments.

2. HUMAN FACTORS TESTING

The following paragraphs describe the human factors involved in the engineering tests required to determine the compliance of the test item to preferred human factors engineering standards of equipment design as indicated in established military standards and specifications, and criteria specified for a particular item.

2.1 CONTROL-DISPLAY RELATIONSHIPS

The degree to which the test item design contributes to ease of opera-

tion through incorporation of: (1) the compatibility between the movement and location, (2) the physiological and anatomical efficiency with which the operator can utilize the control and display, is determined as follows:

a. Noting if the switches are arranged in a logical order of use and priority.

b. Noting if there is enough space between controls.

c. Noting if controls are plainly marked and identified.

d. Noting if controls incorporate good design principles such as clockwise rotation for "on" and counter-clockwise rotation for "off", etc.

e. Noting comfort of operator and whether confusion is caused during operation by similar controls, displays, etc.

f. Use of a checklist to rate the test item during operation relative to the following aspects:

1) Priority of positions
2) Control-display associations
3) Direction of movement relationships
4) Appropriateness of types of displays and controls to the particular item to be tested.

g. Obtaining operator's comments to all of the above aspects through use of a questionnaire.

h. Ensuring that the test personnel are informed of the progress and results of the testing in a timely manner to maintain proper motivation and interest.

2.1.1 Control-Display Relationship Evaluation Guidelines

Control-display organization should ensure that the most important displays and controls occupy the central areas. The priority for correct placement can be determined by an analysis of how the control or display is used by the operator and its ultimate effect on system performance. The priority can be determined in the following ways:

a. The frequency and extent of use.

b. The accuracy and/or speed with which the display must be read or the control positioned.

c. The decrease in system performance and/or safety resulting from an error or delay in using it.

d. The ease of manipulating certain controls in various locations (in terms of the force that can be applied and the precision and speed of adjustment).

2.1.2 Control-Display Associations

Whenever an operator must use a large number of controls and/or displays, their location should aid him in determining the following:

a. Which controls are used with which displays
b. Which equipment component each control affects
c. Which equipment component each display describes

2.1.3 Direction-of-Movement Relationships

The direction of movement of a control should be related appropriately to the change that it induces in the associated display, the equipment component, and/or the system as a whole. Correct direction-of-movement relationships will improve system performance by reducing learning time, decisions and reaction time, and reversal error due to control movement in the wrong direction. Correct relationships enhance speed and precision of control adjustment. Direction-of-movement relationships should satisfy the basic requirement of standardization, consistency, and natural relationships. Natural relationships refer to control movement habit patterns that are consistent from person to person without special training or instructions, i.e., they are responses that individuals make most often and are called "population stereotypes." For example, an upward movement of a toggle switch is almost always related to "on" as opposed to "off." The direction of movement of the control should be considered in relation to the following factors:

a. The location and orientation of the operator relative to the control and to any moving equipment which it activates.
b. The position of the display relative to the control and the nature and direction of the display response.
c. The change exhibited by an equipment component as the result of the control movement - either in terms of motion for moving components (e.g., steerable antenna) or in terms of power for stationary components (volume of a radio receiver, brightness of a radar scope, etc.).

Direct movement relationships should be used whenever possible, and control movements should be consistent for all equipment that the same operator is likely to use.

2.2 VISUAL DISPLAYS

Meters, radar scopes, warning lights, and other displays translate machine inputs into visual information which the human operator can quickly understand and convert into decisions and control actions. Properly designed displays must be suited to the particular conditions of use, and should not contain more than is necessary nor should they be more accurately displayed than the inherent limitations of mechanical instrumentation or human visual capabilities or ambient viewing conditions warrant.

The evaluation of a visual display should include the following:

a. The specificity, accuracy, limitations, and direct usability of the information displayed.
b. The visibility and legibility of the display with respect to location, accessibility, viewing distance, viewing angle, and illumination.
c. The grouping and arrangement of displays according to function, sequence of use, frequency of use, and the consistency from application to application.
d. The appropriate use and uniformity of coding techniques relative

to the following:

1) Discrimination between individual displays
2) Identification of functionally related displays
3) Indication of the relationship between displays
4) Identification of critical information within a display

2.2.1 Methods of Use

An analysis should be made of the type of action the operator will be expected to take upon viewing information from the displays. Generally, displays are used in one or more of the following ways:

a. For Quantitative Reading - This is a reading to an exact numerical value such as reading time from a clock and voltage from a voltmeter.

b. For Qualitative Reading - This is judging the approximate value, trend, rate of change, or direction of deviation from a desired value such as the veering in direction of a tracked target and rising temperature of equipment.

c. For Check-Reading - This is verifying that a desired value is or is not being maintained, such as monitoring a group of dials intermittently for deviation from a normal position.

d. For Setting - This is adjusting a display to a desired position or value. For example, setting a desired temperature on a thermostat.

e. For Tracking - This is intermittent or continuous adjustment of a display to maintain a moving target or reference marker (pursuit tracking).

f. For Spatial Orientation - This is judging position and movement in one place or in three dimensions. Navigation and fire control displays are usually of the spatial-orientation type.

2.2.2 Symbolic and Pictorial Displays

The purpose to be served usually determines the kind of display required. There are two basic kinds of displays: symbolic and pictorial. In symbolic displays, the information presented has no pictorial resemblance to the conditions represented. Words, abbreviations, letters, numbers, mathematical shorthand, and color coding are used. Such parameters as temperature, pressure, and voltage are always presented symbolically. Usually, symbolic displays save panel space and permit a less complex display mechanism. Displays which have a degree of pictorial, geometric, or schematic resemblance to the things they represent are considered pictorial, e.g., television, PPI radar scopes, and attitude indicators. Pictorial displays are useful for showing relationships and orientation in space. Properly designed pictorial displays can generally be interpreted more easily than purely symbolic indicators for the same functions. Usually, pictorial displays are much simplified pictures with symbolic representations added.

2.2.3 Mechanical Indicators

Mechanical indicators are those in which information is presented symbolically or pictorially by means of one or more moving elements. The moving element might be a pointer or a pictorial reference marker. (See Figure A-3.)

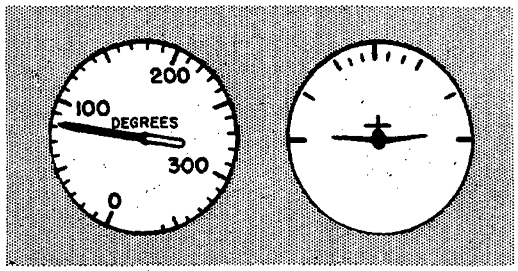


Figure A-3. Pointer and Pictorial Marker as Moving Elements

The moving element is usually the pointer or reference marker, but in some cases the scale, or both scale and pointer might move. The most frequently used types of mechanical indicators and their preferred characteristics are discussed in succeeding paragraphs.

2.2.3.1 Basic Types of Indicators

There are three basic types of symbolic indicators (see Figure A-4). The direct reading counter (A), the moving pointer with fixed scale (B), and the moving scale with fixed index (C). The preferred type of indicator depends upon the particular application or use. Table A-I lists the relative advantages and disadvantages of the three basic indicator types with reference to the method of use.

2.2.3.2 Variations of Basic Types of Indicators

There are several variations of the last two basic types of indicators (B and C, Figure A-4). These variations are:

a. Circular and curved scale with moving pointer. This design (A in Figure A-5), is generally recommended. The circular scale is preferred to the curved scale for most applications.

b. Vertical and horizontal straight scale with moving pointer. This design (B) is especially desirable for short-scale indicators. However, the shorter pointer and lack of rotational movement makes it more difficult to notice change in the position of the pointer.

c. Circular and curved scale with fixed index (C). The partially exposed scale is generally recommended for saving panel space, except for indicators used in tracking, which should have the full scale exposed.

d. Vertical and horizontal straight scale with fixed pointer (D). In this design, a moving scale behind an open window is provided by a moving straight scale, drum or tape. The moving tape is particularly suitable for presenting a large range of values. Several levels of scale complexity are shown in Figure A-6.

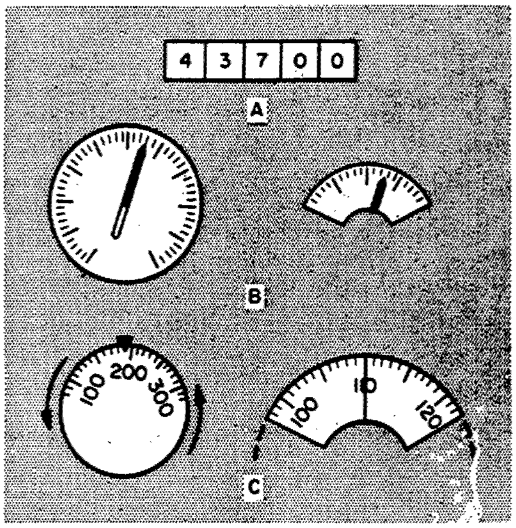


Figure A-4. Basic Types of Symbolic Indicators

Table A-I. Relative Evaluation of Basic Symbolic-Indicator Types

For . . .	*Moving pointer is . . .*	*Moving scale is . . .*	*Counter is . . .*
Quantitative reading	Fair	Fair	Good (Requires minimum reading time with minimum reading error)
Qualitative and check reading	Good (Location of pointer and change in position is easily detected)	Poor (Difficult to judge direction and magnitude of pointer deviation)	Poor (Position changes not easily detected)
Setting	Good (Has simple and direct relation between pointer motion and motion of setting knob, and pointer-position change aids monitoring)	Fair (Has somewhat ambiguous relation between pointer motion and motion of setting knob)	Good (Most accurate method of monitoring numerical settings, but relation between pointer motion and motion of setting knob is less direct)
Tracking	Good (Pointer position is readily monitored and controlled, provides simple relationship to manual-control motion, and provides some information about rate)	Fair (Not readily monitored and has somewhat ambiguous relationship to manual-control motion)	Poor (Not readily monitored, and has ambiguous relationship to manual-control motion)
General	Good (But requires greatest exposed and illuminated area on panel, and scale length is limited)	Fair (Offers saving in panel space because only small section of scale need be exposed and illuminated, and long scale is possible)	Fair (Most economical in use of space and illuminated area, scale length limited only by number of counter drums, but is difficult to illuminate properly)

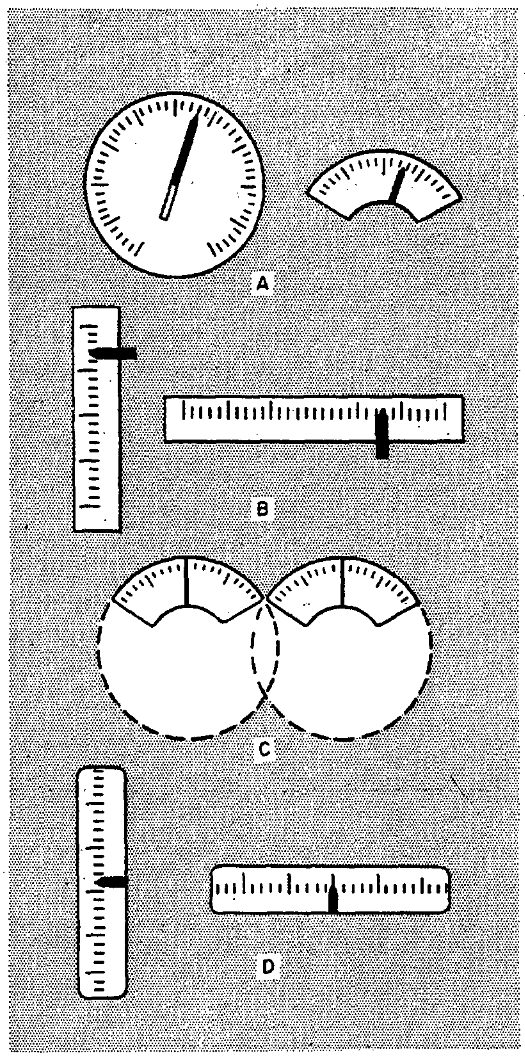


Figure A-5. Variations of Basic Mechanical Indicators

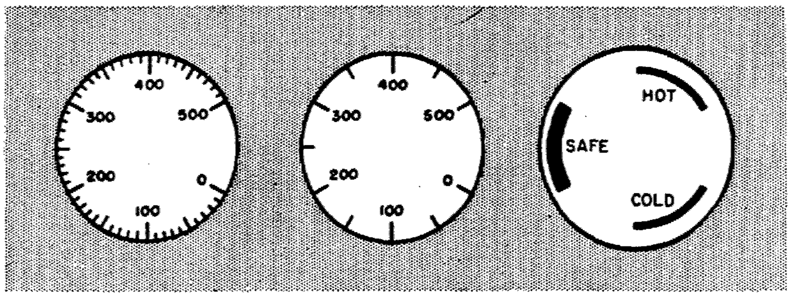


Figure A-6. Degrees of Scale Complexity

2.2.3.3 Interval Values

Some combinations of graduation interval values and scale numbering systems are more satisfactory than others. The following recommendations will be useful for evaluating the suitability of indicators. (See Figure A-7 and Table A-II.)

Table A-II. Examples of Good, Fair, and Poor Progressions for Scale Numbers

Good					Fair					Poor				
0.1	0.2	0.3	0.4	0.5	0.2	0.4	0.6	0.8	1.0	0.25	0.5	0.75	1.0	
1	2	3	4	5	2	4	6	8	10	2.5	5	7.5	10	
10	20	30	40	50	20	40	60	80	100	25	50	75	100	
100	200	300	400	500	200	400	600	800	1000	250	500	750	1000	
0.5	1.0	1.5	2.0	2.5						0.4	0.8	1.2	1.6	1.8
5	10	15	20	25						4	8	12	16	18
50	100	150	200	250						40	80	120	160	180

The graduation-interval values should be one, two, five, or decimal multiples thereof. Graduation-interval values of two are somewhat less desirable than values of one or five. Table A-II gives examples of good, fair, and poor numerical progressions.

The number of graduation marks between numbered graduation marks should not exceed nine, i.e., there should be no more than ten graduation intervals.

Normally, scales numbered by intervals of 1, 10, 100, etc., and subdivided by ten graduation intervals, are superior to other acceptable scales.

It is generally recommended that scales be designed so that interpolation between graduation marks is not necessary, but when space is limited, it is better to require interpolated readings than to clutter the dial with crowded graduation marks.

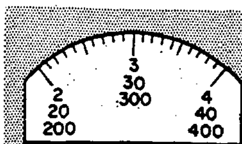
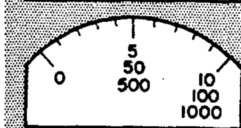
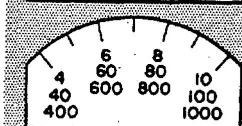
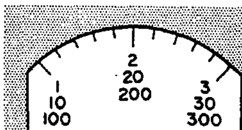
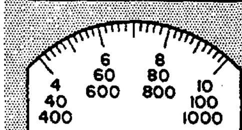
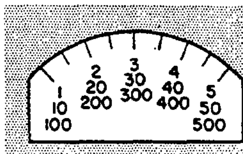
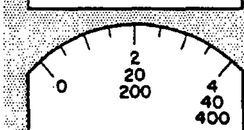
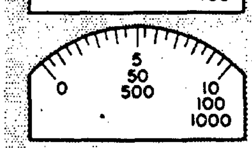
GRADUATION INTERVAL VALUE	RECOMMENDED SCALES	NUMBERED INTERVAL VALUE	GRADUATION MARKS		
			MAJOR	INTERMEDIATE	MINOR
0.1, 1, 10		1, 10, 100	X	X	X
		5, 50, 500	X		X
		2, 20, 200	X	X	
0.2, 2, 20		1, 10, 100	X		X
		2, 20, 200	X	X	X
0.5, 5, 50		1, 10, 100	X	X	
		2, 20, 200	X	X	X
		5, 50, 500	X	X	X

Figure A-7. Recommended Scale Graduation and Interval Values

2.2.3.4 Scale Interpolation

In general, scales that are to be read quantitatively should be designed so that interpolation between graduation marks is not necessary; scales should be designed to be read to the nearest graduation mark. For instance, if we assume a scale range of 50 and a scale that is to the nearest unit, the preferred scale would be numbered by tens with a graduation mark for each unit as shown in Figure A-8 (A). If the space available for this scale were restricted to 2 inches, the same scale would appear as in Figure A-8 (B), but the graduation marks on this scale are too crowded to be read accurately and rapidly under low illumination; the midpoints are only 0.04 inch apart, and this is 0.03 inch less than the recommended minimum. In situations such as this, a scale requiring interpolation is better (for example, C in Figure A-8). This scale has a graduation-mark spacing of 0.08 inch which is acceptable for low illumination. Also, this scale requires only a simple interpolation of one unit between graduation marks. When space is greatly limited, it might be necessary to interpolate in fifths or even tenths, but such interpolation will increase reading errors.

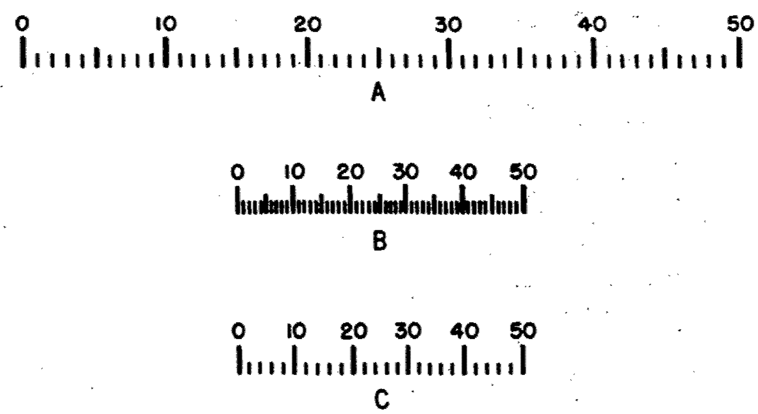


Figure A-8. Scale Interpolation

2.2.4 Transilluminated Indicators

Transilluminated indicators are of three general types as follows:

a. Single and multiple legend lights, which present information in the form of meaningful words, numbers, symbols, or abbreviations.

b. Simple indicator lights, such as pilot, bull's eye, and jewel lights.

c. Transilluminated panel assemblies, which present whole patterns of information.

Transilluminated indicators are used to display qualitative information to the operator, and should be used primarily for information that requires immediate action or to bring attention to an important system status. Such indicators may also be used occasionally for maintenance and adjustment functions. However, the use of status or caution signals is sometimes overdone, with the result that large arrays of lights are provided that dazzle and confuse the operator. Lights and related indicators should be used sparingly, and should display only that information necessary for effective system operation.

2.3 AUDITORY WARNING DEVICES

Audio techniques for the display of information have not been utilized to the fullest extent in equipment design. Auditory signals in conjunction with visual signals, however, in some instances have demonstrated a decided advantage over either type of signal alone. The major advantage of auditory signals is in the fact that an operator can act upon the information he receives without being oriented toward the source of the signal. The most apparent disadvantage of the auditory signal is the short time span during which the operator is subjected to the signal.

Auditory warning devices have two major applications in military equipment. These are:

a. Warning Signals - Audio signals such as bells, buzzers, horns, whistles, sirens, or tones are used to:

1) Warn personnel of impending danger.
2) Alert an operator to a critical change in system or equipment status.
3) Remind the operator of a critical action or actions that must be taken.

b. Caution Signals - Caution signals, which must be readily distinguishable from warning signals, are used to indicate conditions requiring awareness, but not necessarily immediate action.

An evaluation of auditory warning devices should consider the following aspects for comparison to applicable criteria:

a. Appropriateness for the application.
b. Relationship to any associated visual display.
c. Intensity and direction.
d. Frequency range.
e. Audibility under ambient noise conditions.
f. Distinguishability from other auditory warning and caution signals.
g. Differentiation from routine auditory signals (e.g., telephone bells, buzzers, normal operational noises).
h. Masking of other critical auditory signals.
i. Controls (ease of identification and use).

2.4 CONTROLS

2.4.1 General

The design, type, and location of controls are important factors affecting operator performance in most man-machine systems. The suitability of any control depends on its appropriateness for the task to which it is assigned. When evaluating the suitability of controls, consider the following:

a. The function of the control - its purpose and importance, the nature of the controlled object or display, and the type, extent and direction of change to be accomplished.

b. Requirement of the task - speed, range, precision and force requirements, and the effect of reducing one of these to improve another.

c. Informational needs of the operator - locating and identifying the control, determining control setting, and sensing any change in control position.

d. Requirements imposed by the work space.

e. Direction of movement of the control in relation to the associated controlled object or display.

f. Distribution of work load between right and left hands, and between hands and feet when applicable.

2.4.2 The Control-Display Ratio

The control-display (C/D) ratio is the ratio of the distance of movement of the control to that of the moving element of the display (pointer, cursor, etc.). The C/D ratio is a critical factor affecting time and accuracy of operator performance.

For linear and near-linear controls (e.g. levers) that affect linear displays, the C/D ratio is defined as the ratio of the linear distance of control displacement being measured from the point where the operator's hand grasps the control (see Figure A-9). For small rotary controls (e.g. knobs) that affect linear displays, the C/D ratio is the ratio of the number of control rotations to the distance of display movement.

When evaluating the appropriateness of the C/D ratio, the following factors which affect the optimum ratio should be kept in mind:

a. Tolerance - Fine adjusting time is reduced directly by easing the tolerance requirements.

b. Display size - With tolerance kept constant, size of the display can affect total adjustment time.

c. Time delay - The type and extent of any time delay in the system might affect the optimum C/D ratio. For exponentially shaped time delays that occur between the control movement and the resulting display response, the longer the time delay (within reasonable limits), the smaller will be the optimum C/D ratio.

d. Control positioning - Positioning a continuous adjustment control requires a primary or slewing movement, followed by a fine-adjusting

movement to place the control precisely in the final, desired position. An increase in the C/D ratio will increase slewing time because of the longer movements required. The optimum C/D ratio is that which minimizes the total time (slewing plus fine adjusting) required to make the desired control movement.

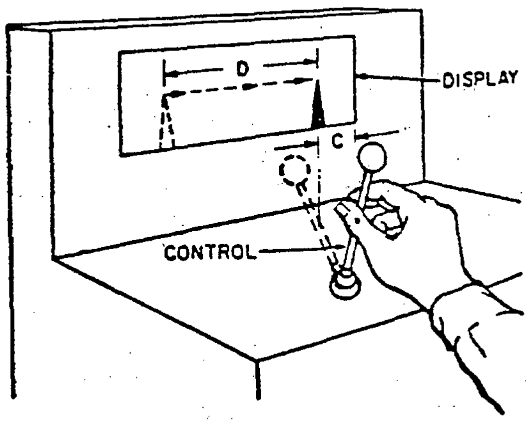


Figure A-9. Linear C/D Ratio

2.4.3 Direction of Control Movement

A major requirement is that a control move in the "expected direction, producing a machine or display movement in a similar direction. For example, a control movement to the right of clockwise should cause the machine or display to which it is linked to move to the right or clockwise. In addition, the movement should not change in direction, but, if it does, continuous, curved movements should be used.

Where great strength must be exerted on a control, push-pull movements should be used. Rotation produces the next highest force, followed in descending order by up-down and right-left movements. In the weakest direction (right-left), control movements are only about one-third as strong as those exerted in the strongest direction (push-pull).

For precision, a single control moving in two or three dimensions is better than separate ones, each moving in one dimension. Right-handed operators move indicator knobs most precisely between 9 and 12 o'clock with the right hand and between 12 and 3 o'clock with the left hand. Where

possible, control movement should be terminated by a fixed, mechanical stop rather than by muscular control guided by sight or touch.

2.4.4 Speed of Movement

For speed in control movement, the required precision of movement should be as low as possible because increasing the precision required increases the operating time. Generally, control resistance should be minimal, though a pound or two makes little difference, because control speed decreases as the load increases.

The distance moved should be as short as possible because longer movements take more time. Longer movements take proportionately less time, however. For instance, a 4-inch movement will take 0.8 second, whereas a 16-inch movement will take only 1.0 second. This is because reaction time and starting time are constant regardless of distance moved, and longer movements permit increasing rates of movement.

The preferred direction of movement for most hand controls is horizontal rather than vertical and fore-and-aft rather than lateral. Horizontal movements generally are faster than left-right for right-handed operators; but, for short linear movements of about 2-3 inches long that require precision, vertical movements are fastest, followed by lateral and fore-and-aft movements.

Handwheels are turned most rapidly when the wheel is nearly vertical. For handwheels and cranks, speed of movement varies with control resistance and radius (slower speed with largest resistance and radius), but 180 rpm is a good "average" speed. Handwheels and cranks should be turned forward of clockwise for maximum speed and efficiency. Two-hand, simultaneous, positioning movements are fastest when reaching about 30 degrees to the left and right of the midplane of the body.

2.4.5 Control Resistance

Some force must always be applied to make a control move. The kinds of resistance offered by the control (and the device to which it is coupled) are listed as follows:

a. Elastic (spring loading)
b. Static and sliding friction
c. Viscous damping
d. Inertia

Rarely, if ever, is control resistance of a single kind. All controls have some mass and hence, some inertia; most controls move on a slide, shaft, or pivot and, hence, have some static and sliding friction. In addition, in terms of operator performance, there are interactions among the various kinds of resistance; friction or viscous damping, for example, can be helpful in counteracting the adverse effects of excessive inertia.

Depending on the kind and amount, resistance can affect the following:

a. The precision and speed of control operation.
b. The "feel" of the control.
c. The smoothness of control movement.
d. The susceptibility of the control to accidental activation and to the effects of shock, vibration, g forces, etc.

2.4.5.1 Resistance Measurements

For toggle switches, handwheels, cranks and levers, resistance is measured in terms of linear resistance (i.e., the resistance at the point where the operator applies force to the control) rather than torque. For these controls, operator output normally can be considered as a force relatively independent of control radius. For circular knobs, resistance is measured in terms of torque. The force, that can be brought to bear on these controls is a function of the "efficiency" of the operator's grasp (i.e., the amount by which the fingers must be spread, etc.), which, in turn, is related to knob diameter.

2.4.6 Control Coding

Controls are often coded to make them easier to identify quickly. The most common methods of coding are shape, size, color, labeling, location, and mode-of-operation. Advantages and disadvantages of various types of coding as well as preferred types and amounts of resistance for various types of controls are given in Figures A-10, and A-11, and Tables A-III, A-IV, A-V, A-VI, A-VII, and A-VIII.

Knobs lend themselves well to shape-coding and for this purpose can be divided into three classes; A, B, and C. (See Figure A-10). Each knob can be identified by touch alone with the bare hand or while wearing light-weight gloves. These knobs may be used together without confusing one with the other, with the following exceptions:

a. Knobs of class A-3 should not be used with those of B-4
b. Knobs of class B-4 should not be used with those of B-5
c. Knobs of class B-2 should not be used with those of B-3 or B-4

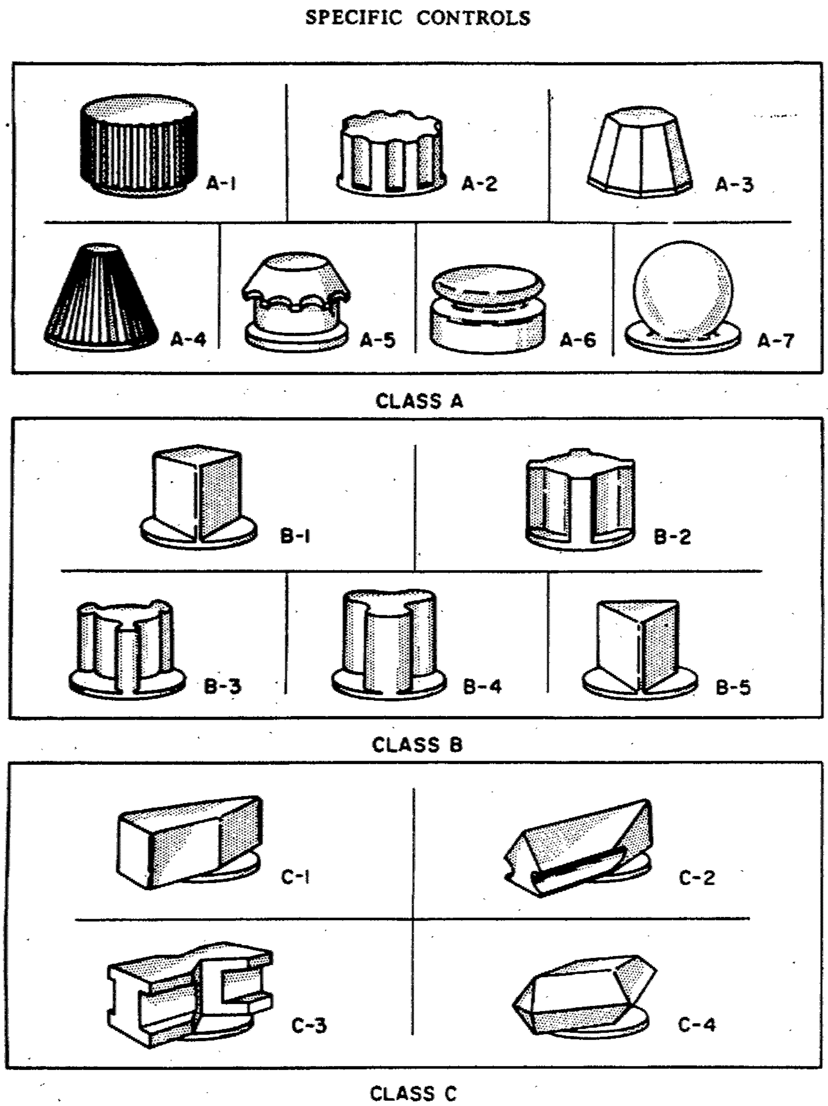


Figure A-10 Examples of Shape Coded Knobs

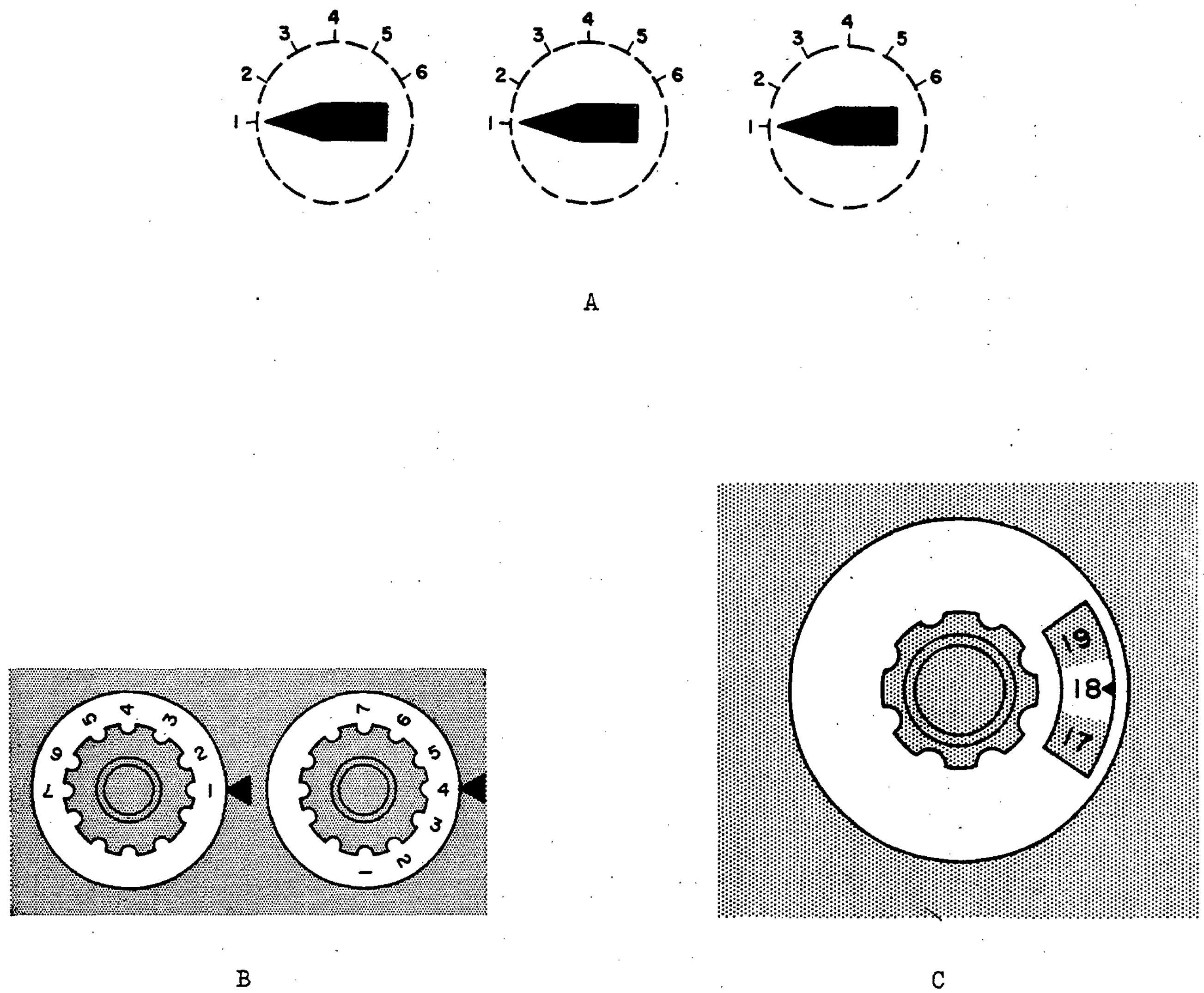


Figure A-11 Several Types of Rotary Switches

Table A-III. Advantages and Disadvantages of Various Types of Coding

ADVANTAGES	TYPE OF CODING					
	LOCATION	SHAPE	SIZE	MODE OF OPERATION	LABELING	COLOR
Improves visual identification.	X	X	X		X	X
Improves nonvisual identification (tactual and kinesthetic).	X	X	X	X		
Helps standardization.	X	X	X	X	X	X
Aids identification under low levels of illumination and colored lighting.	X	X	X	X	(When trans-illuminated)	(When trans illuminated)
May aid in identifying control position (settings).		X		X	X	
Requires little (if any) training; is not subject to forgetting.					X	
DISADVANTAGES						
May require extra space.	X	X	X	X	X	
Affects manipulation of the control (ease of use).	X	X	X	X		
Limited in number of available coding categories.	X	X	X	X		X
May be less effective if operator wears gloves.		X	X	X		
Controls must be viewed (i.e., must be within visual areas and with adequate illumination present).					X	X

Table A-IV. Comparison of the Characteristics of Common Controls

Characteristic	Hand push-button	Foot push-button	Toggle switch	Rotary switch	Knob	Crank	Lever	Hand-wheel	Pedal
Space required	Small	Large	Small	Medium	Small-medium	Medium-large	Medium-large	Large	Large
Effectiveness of coding	Fair-good	Poor	Fair	Good	Good	Fair	Good	Fair	Poor
Ease of visual identification of control setting	Poor [1]	Poor	Fair-good	Fair-good	Fair-good [2]	Poor [3]	Fair-good	Poor-fair	Poor
Ease of tactile identification of control setting	Poor	Poor	Good	Fair-good	Poor-good	Poor [3]	Poor-fair	Poor-fair	Poor-fair
Ease of check reading in array of like controls	Poor [1]	Poor	Good	Good	Good [2]	Poor [3]	Good	Poor	Poor
Ease of operation in array of like controls	Good	Poor	Good	Poor	Poor	Poor	Good	Poor	Poor
Effectiveness in combined control	Good	Poor	Good	Fair	Good [4]	Poor	Good	Good	Poor

[1] Except when control is backlighted (see Chapter 2) and light comes on when control is activated.
[2] Applicable only when control makes less than one rotation and when round knobs have pointer attached.
[3] Assumes control makes more than one rotation.
[4] Effective primarily when mounted concentrically on one axis with other knobs.

Table A-V. Control Size Dimensions

REQUIREMENT	HAND PUSH BUTTONS	FOOT PUSH BUTTONS	TOGGLE SWITCHES	DISC KNOBS	CONT KNOBS	CRANKS	HAND-WHEELS	DISC THUMB WHEELS	LEVERS	PEDALS
MINIMUM:										
One-finger random	1/2"		3/4"							
One-finger sequential	1/4"		1/2"							
Different fingers	1/2"		5/8"							
One-hand random				1"	1"	2"			2"	
Two-hands simultaneously					2"	3"	3"		3"	
Two-hand operation				3"						
One-foot random										4"
One-foot sequential										2"
PREFERRED:										
One-finger random	2"		2"							
One-finger sequential	1"		1"							
Different fingers	1/2"		3/4"							
One-hand random				2"	2"	4"			4"	
Two-hands simultaneously					5"	5"	5"		5"	
Two-hand operation				5"						
One-foot random										6"
One-foot sequential										4"
MAXIMUM:										
Group of levers operated simultaneously by one hand									6"	

Table A-VI. Control Separation

REQUIREMENT	HAND PUSH BUTTONS	FOOT PUSH BUTTONS	TOGGLE SWITCHES	DISC KNOBS	CONT KNOBS	CRANKS	HAND-WHEELS	DISC THUMB WHEELS	LEVERS	PEDALS
MINIMUM:										
Length										3"
Finger Operation			1/2"	1"						
Hand operation										
Cylinder encircled by thumb/fingers				3"						
Width					NL		3/4" rim thickness	1/4"		1"
Depth				5/8"				1/8"		
Finger operation					1/2"					
Hand operation										
Cylinder encircled by thumb/fingers										
Diameter		1/2"				1/2" Rad				
Finger operation	1/2"		1/8" tip		3/8"			1-1/2"	1/2" *	
Hand operation	3/4"				1-1/2"	1/2" Rad	7"		1-1/2" *	
Cylinder encircled by thumb/fingers					1"					
MAXIMUM:										
Length			2"							
Width				1"			2" rim thickness	1/2"		
Depth				3"				1/2"		
Finger operation					1"					
Hand operation										
Cylinder encircled by thumb/fingers										
Diameter										
Finger operation			1" tip		4"			2-1/2"		
Hand operation					3"	20" **	21" ***			
Cylinder encircled by thumb/fingers					3"				3" *	

Table A-VII Control Resistance

REQUIREMENT	HAND PUSH BUTTONS	FOOT PUSH BUTTONS	TOGGLE SWITCHES	DISC KNOBS	CONT KNOBS	CRANKS	HAND-WHEELS	DISC THUMB WHEELS	LEVERS	PEDALS
MINIMUM:										
Finger operation	10 oz		10 oz	1 in-lb	No Minimum Estab-lished			1 in-lb	12 oz	
Hand operation							5 lb		2 lb	
Foot rests on control		10 lb								10 lb
Foot not on control		4 lb								4 lb
Small (less than 3-1/2")						2 lb				
Large (5 to 8"): Rapid, steady turning						5 lb				
Precise settings						2-1/2 lb				
MAXIMUM:										
Finger operation:	40 oz		40 oz	6 in-lb				3 in-lb		
Small (1" or less)					4-1/2 in-oz					
Large (more than 1")					6 in-oz					
Ankle flexion only		20 lb								10 lb
Leg movement										180 lb
Small (less than 3-1/2")						5 lb				
Large (5 to 8"): Rapid, steady turning						10 lb				
Precise settings						8 lb				
One-hand operation							30 lb			
Two-hand operation							50 lb			
Fore-aft: One-hand, along median plane: 10 in. forward of SRP									30 lb	
16-24 in. forward of SRP									50 lb	
Two-hand, 10-19 in. forward of SRP									60-100 lb	
Lateral: One-hand, 10-19 in. forward of SRP									20 lb	
Two-hand, 10-19 in. forward of SRP									30 lb	

Table A-VIII. Control Displacement

REQUIREMENT	HAND PUSH BUTTONS	FOOT PUSH BUTTONS	TOGGLE SWITCHES	DISC KNOBS	CONT KNOBS	CRANKS	HAND-WHEELS	DISC THUMB WHEELS	LEVERS	PEDALS
MINIMUM:										
For normal operation	1/8"	1/2"								1/2"
For heavy boots		1"								1"
Between adjacent positions			30°							
Between detents: Visual positioning				15°						
Nonvisual positioning				30°						
Determined by desired C/D ratio					XX	XX	XX			
Determined by number of positions								XX		
None established									XX	
MAXIMUM:										
For thumb or fingertip operation	1-1/2"									
For ankle flexion only		2-1/2"								2-1/2"
For leg movements		4"								7"
Total displacement			120°							
For facilitating performance				40°						
When special engineering required				90°						
Determined by desired C/D ratio					XX	XX				
Provided optimum C/D ratio not hindered							90-120°			
Determined by number of positions								XX		
Fore-aft movement									14"	
Lateral movement									38"	

Controls can be coded by size, but the number of sizes that can be used is limited. The ability to discriminate shape, however, is relatively independent of size so that size coding can be superimposed on shape coding. Both size and shape coding are less effective if the operator wears thick gloves. When the operator cannot compare the sizes of all controls before selecting the proper one, only two or three different sizes of controls should be used (viz., small, medium, and large). Where the operator always compares two controls before selecting the proper one, three, four or five different sizes of controls may be used.

Color coding establishes relationships from one equipment to another, and is most effective when a special meaning can be attached to the color (e.g., red for danger). Color should not generally be used as the primary method for coding controls, but it is effective when combined with other methods. When controls are associated with transilluminated and simple indicators, color coding should be compatible with that of the visual display.

Location or position coding, in which controls associated with similar functions are in the same relative location from panel to panel, permits the operator to establish a habit pattern and reduces the requirement for use of other coding methods. The more definitive the spacings, the sooner the operator establishes accurate habit patterns.

The mode of operation of a control is a useful method of identifying it. This method of coding improves nonvisual identification, but it is limited in that the operator must activate or attempt to activate the control in order to identify it.

All controls should be designed and located so that they are not susceptible to being moved accidentally. Particular attention should be paid to critical controls whose inadvertent operation might cause damage to equipment, injury to personnel, or delay in system functions. The method or methods used for protection against accidental operation should not compromise other human factors considerations to an unacceptable degree.

2.4.7 Recommended Characteristics for Specific Controls

2.4.7.1 General

These paragraphs contain discussions of the most commonly used controls and present recommended characteristics for the various types and applications. A compromise of the characteristics of common controls is contained in Table A-IV. Specific recommendations for control size, control separation, control resistance, and control displacement for each type and requirement are summarized in Tables A-V, A-VI, A-VII, and A-VIII.

2.4.7.2 Rotary Switches

Rotary selector switches are used for discrete functions when three or more detented positions are required. Normally, they should not be used for

a two-position function, unless ready visual identification of control position is of primary importance and speed of control operation is not critical.

Rotary switches usually have between 3 and 24 settings (positions). They may have more, but speed and accuracy of setting and checking are sacrificed if they do. These switches require a medium amount of space for operation because of the swept volume of the hand. When a large number of discrete settings is needed, however, one rotary selector switch requires less space than an array of push-buttons or toggle switches. Rotary switches are quickly activated and easily coded by color or shape, and control setting (position) can be identified visually and nonvisually if properly designed. Rotary switches can have either a moving pointer and a fixed scale or a moving scale and fixed index, but a moving pointer with a fixed scale is preferred for most tasks.

The moving-pointer type can conform with direction-of-motion relationships without violating other principles, and it facilitates check reading control position for individual controls and for arrays of controls (see A, Figure A-11). With the moving-scale type, the setting always reads from the same position (see B, Figure A-11) but the index can be located at any one of the four cardinal points, depending on which is most desirable for the specific situation. In addition, a small segment of the entire scale is all that need be shown. With the open-window arrangement shown in C, Figure A-11, the clutter of numbers on the panel is reduced to a minimum.

2.4.7.3 Hand Pushbuttons

Pushbuttons are usually used when a control or array of controls is needed for momentary contact or for activating a locking circuit, particularly in a high-frequency-of-use situation.

Hand pushbuttons are of three major types: Push-on-release-off, push-on-push-off, push-on-lock-on. They require only a small amount of space for their location and operation and they can be coded by color or size. They can be operated quickly and simultaneously with other pushbuttons in an array and are identified easily by their position within an array or by their associated display signal, but control setting (whether "on" or "off") is not identified easily either visually or nonvisually. Although they can be very quickly activated, operating time increases with excessive displacement and/or resistance.

2.4.7.4 Foot Pushbuttons

Foot-operated pushbuttons are generally used only in those cases where the operator is likely to have both hands occupied when the control is needed, or when load sharing among many controls is required.

Foot pushbuttons are of two major types: push-on-release-off, and push-on-push-off. They leave the hands free for other operations, but require a large amount of space for their operation because of the swept volume of the foot. Because it usually cannot be seen or felt (without danger of

activating it), neither the control nor its setting (whether "on" or "off") is easily identified, but it is quickly activated when the foot is on it. Operating time increases with increase in required displacement and/or resistance, and toe-operated controls are activated slightly faster than heel-operated ones.

Because foot pushbuttons are extremely susceptible to accidental activation, their use should be limited to noncritical operations such as press-to-talk switches.

2.4.7.5 Toggle Switches

Toggle switches are generally used for those functions which require two discrete positions, or where space limitations are severe. Toggle switches are discrete position controls; small controls of the same size and shape, but used for making continuous adjustments, are classified as levers.

Toggle switches usually have two positions; they may have more, but speed and ease of operation are sacrificed if they do. These switches require only a small amount of space for their proximity to the associated display or by their location within an array. Control setting (position) is identifiable both visually and nonvisually, provided the switch has a small number of positions (preferably two, but three are acceptable).

2.4.7.6 Knobs

Knobs are normally used for precise adjustments of a continuous variable when little force is required. They are effective for making small turning operations that do not require the application of large forces, and they require only a small-to-medium amount of space for their operation because of the swept volume of the hand. They are easily coded by color, size, or shape; and control setting (position) is visually identifiable if the control makes less than one rotation and has a pointer or marker attached.

Knobs can have an unlimited range of control movement, and, with proper gearing, they can be used for either gross or fine positioning over a wide range of adjustments. In addition, a folding crank handle can be attached to the knob to aid in rapid slewing. Knobs can be "ganged" by mounting them on concentric shafts. Mounting more than two knobs on the same shaft, however, is likely to be wasteful, of panel space, but it might be desirable for other reasons such as facilitating a sequence of operations.

Within the ranges recommended in Table A-V, knob size is relatively unimportant provided the C/D ratio is optimum, the resistance is low, and knob easily grasped. When panel space is limited, the use of minimum values for knob size will not degrade performance, provided that knob resistance is low as possible without permitting the setting to be changed by merely touching the control.

Knob diameters have little effect on speed and accuracy. Diameters of 1 1/2 - 2 inches are generally acceptable. Diameters of 2 inches provide

smooth operation at any resistance (1 3/4 - 3 1/2 ounces or less). If resistances are above 5 1/4 - 7 ounces, knob diameters should be at least 1 1/2 inches in diameter.

For concentric, ganged knobs, the best arrangement is with knobs greater than 1/2 inch in diameter and 3/4 - 1 1/4 inches between their edges. Where three knobs are concentric, the best diameters are 1/2 - 1 inch for the front or top knob, 2 inches for the middle one, and 3 1/4 inches for the back or bottom one. Minimum knob depth should be about 1/2 inch, and the best depth is about 3/4 inch.

The kind of resistance that should be provided depends, primarily, on performance requirements. When other kinds of resistance are satisfactory for precise positioning tasks, changes in inertial resistance have little practical effect on performance until an excessive level is reached. Finger-operated knobs used for fine adjustment should have 1 - 2 inches of pointer movement for one complete turn of the knob. If less pointer movement is required, lower ratios (less pointer movement per turn of knob) should be provided; for more pointer movement, higher ratios should be provided. In general, accuracy increases as the ratio decreases.

2.4.7.7 Cranks

Cranks are used primarily for tasks requiring many rotations of a control, particularly where high rates or large forces are involved. Guidelines regarding the use of cranks are provided as follows:

a. Cranks should be used for tasks involving at least two rotations of control movement; knobs and handwheels are better when the task requires less movement.

b. The kind or kinds of resistance to be provided depends, primarily, on performance requirements. In general, however, any resistance will decrease the maximum rate of turning (about 75 rpm). Friction of 2 - 5 pounds reduces the effects of shock, but friction degrades performance in rotating cranks at constant rates; primarily at low rates (3 - 10 rpm), slightly at moderate rates (about 30 rpm), and negligibly at high rates (above 100 rpm). Inertial resistance aids performance in rotating cranks at constant rates, particularly for small cranks and at low rates.

c. The crank handle should be designed so that it turns freely around its shaft.

Cranks are effective in making adjustments on a continuum when large distances must be covered and high rates of turning are required. For slower rates, a knob or handwheel is more effective. Cranks require a medium-to-large amount of space for their location and operation (turning) because of the swept volume of the hand.

Because cranks are usually multirotational, the position of the crank handle generally does not indicate the control setting (position). Cranks can have an unlimited range of control movement, and, with proper gearing, can be

used for either gross or fine positioning over a wide range of adjustments.

Cranks can be attached to knobs or handwheels to increase the versatility of that control. Under no-load conditions, small cranks can be turned more rapidly than large ones. As the load increases, the crank size that maximizes turning rate also increases (see Figure A-12).

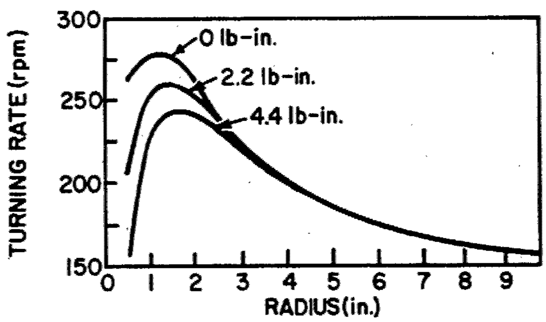


Figure A-12. Ratio of Crank Radius to Turning Rate

2.4.7.8 Levers

Levers are usually used when multidimensional movements of the control are required, or when large amounts of force or displacement are involved. Some specific recommendations are listed below.

Levers include "joysticks", gear shifts, and controls such as aircraft throttles. Levers are usually designed to move when force is applied, but they also may be designed to remain fixed in one position. For these "rigid" (or "pressure") controls, the amount of force being applied is used as the input to the system. Both rigid and spring-loaded levers are characterized by their elastic resistance. Spring-loaded levers are generally preferred because their control positions can be determined visually and because they provide the operator with feedback information about both control position and resistance (thus giving him better "feel"). The primary advantage of rigid levers is that they require no extra space for displacement.

Spring-loaded levers require a medium-to-large amount of space for their location and operation; they are easily coded by color, size, or shape; and control setting (position) can be identified fairly well, both visually and nonvisually (see Table A-IV).

Because they generally have a limited range of movement, however, levers are usually unsatisfactory for precise positioning over a wide range of adjustments. For making large fore-and-aft movements, a long lever is usually more desirable than a short one because the movements of a long lever

are more nearly linear.

Levers are most effective when they move through an arc of not more than 90 degrees, but in any event, the range of movement should never exceed the convenient reach of the arm.

In making very fine adjustments with a small "joystick", operators rest their wrists on the control panel and grasp the control pencil-style below the tip rather than on it. For such situations, the pivot point should be recessed below the surface on which the wrist rests.

2.5 LABELS

The legibility and accessibility of labels used for identifying and operating equipment are critical considerations in emergencies and other circumstances when the operator is pressed for time, and when operating infrequently used or unfamiliar equipment. In an evaluation of labels to determine degree of conformance with general human factors principles and applicable military criteria, the following aspects must be considered:

a. Type of label and suitability for the purpose, including:

1) The accuracy of identification required.
2) The time available for recognition or other response.
3) The distance at which the labels must be read.
4) The illumination level and color characteristics of the illuminating source.
5) Content, including clarity, brevity, and proper use of abbreviations and symbols.
6) Visibility and legibility.
7) Design of label characters.

2.6 WORKSPACE DESIGN AND LAYOUT

2.6.1 General

The locations, size, configuration and accessibility of equipment should be such that it is operable and maintainable by at least the 5th through the 95th percentile group of the user population. The 5th percentile of a particular dimension is a value such that 5 per cent of the personnel are smaller than the value expressed and 95 per cent are larger; conversely, the 95th percentile for a particular dimension is a value such that 95 per cent of the personnel are smaller than the value expressed and 5 per cent of the personnel are larger. When evaluating the workspace design and layout during equipment operation to determine the degree of conformance with applicable human factors criteria for accommodating the intended user, the following factors must be especially noted:

a. Anthropometric data for 5th through 95th percentile military personnel.
b. Gross dimensions required for passages, clearances, etc. (95th percentile).

c. Limiting dimensions for reaching and other movements (5th percentile).

d. Adjustable dimensions for accommodating the full range of users (5th through 95th percentile).

e. Free floor space.

f. Kick space when required.

g. Protrusions on equipment (e.g., handles).

h. Storage space for manuals, tools, and other equipment.

i. For standing operations: Location of displays, controls, indicators and work surfaces with respect to the physical limitations of the user.

j. For seated operations;

1) Location of displays, controls, indicators and work surfaces relative to the physical limitations of the user.
2) Characteristics of seating arrangement.
3) Knee and foot room.

k. Workspace in which work must be accomplished (note unusual positions, e.g., squatting, stooping, kneeling, crawling).

l. Dimensions of console relative to recommended standard console dimensions.

m. Ladders, platforms and elevated work areas.

2.6.2 Anthropometric and Dimensional Data

The anthropometric and dimensional data tabulated and shown in Tables A-IX through A-XII and Figures A-13 through A-16 provide a basis for evaluating the appropriateness of the test item with respect to human factors criteria for the accommodation of equipment and workspace to the limiting physical characteristics of operating and maintenance personnel. Use of these data must take into consideration the following:

a. The nature, frequency, and difficulty of the related tasks.

b. The position of the body during performance of the tasks.

c. Mobility of flexibility requirements imposed by the tasks.

d. Increments in the design-critical dimensions imposed by the need to compensate for obstacles, projections, etc.

e. Increments in the design-critical dimensions imposed by protective garments, padding, etc.

f. Use of Data:

1) Gross Dimensions - (passageways, accesses, safety clearances, etc.) which must accommodate or allow passage of the body should be based on the 95th percentile values.)
2) Limiting Dimensions - (reaching distance, displays, test-points, handrails, control movements, etc.) which restrict or are limited by extension of the body should be based on the 5th percentile value.

Table A-IX. Standing Body Dimensions

KEY TO FIG. A-13	DIMENSION	5TH PERCENTILE	MEAN	95TH PERCENTILE
A	Vertical Reach	77.0	83.6	90.3
B	Stature	65.2	69.1	73.1
C	Eye Height	60.8	64.7	68.6
D	Shoulder Height	52.8	56.5	60.2
E	Elbow Height	40.6	43.5	46.4
F	Wrist Height	31.0	33.5	36.1
G	Knuckle Height	27.7	30.0	32.4
H	Kneecap Height	18.4	20.2	21.9
I	Ankle Height	4.9	5.6	6.8
J	Chest Depth	8.0	9.1	10.4
K	Buttock Depth	7.6	8.8	10.2
L	Functional Reach	29.7	32.3	35.0
M	Depth of Reach	23.0	--	--

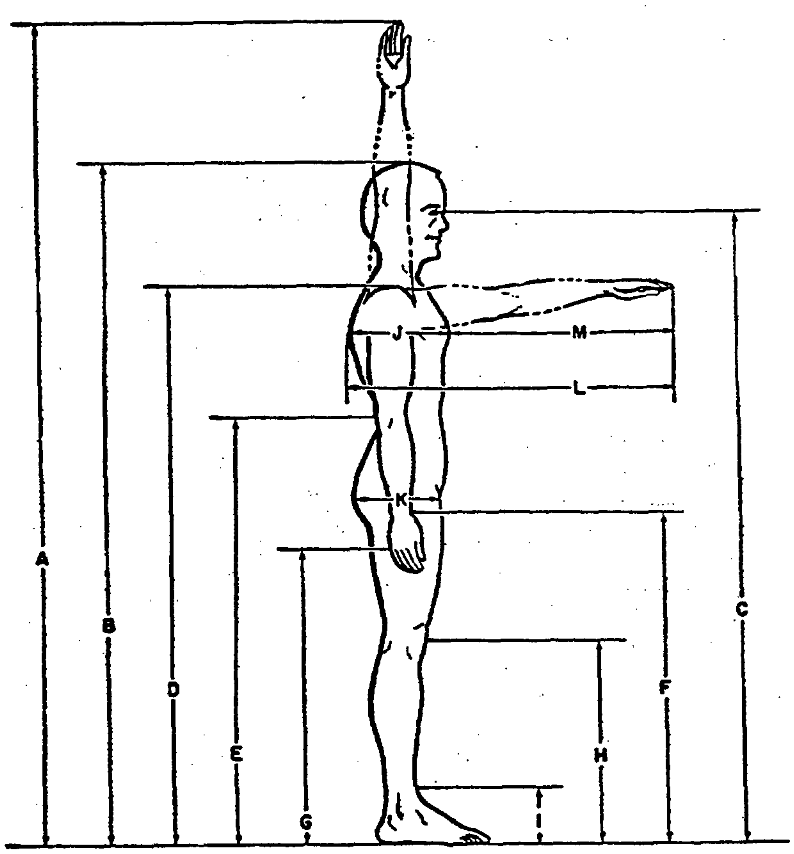


Figure A-13. Standing Body Dimensions

Table A-X. Seated Body Dimensions

KEY TO FIG. A-14.	DIMENSION	5TH PERCENTILE	MEAN	95TH PERCENTILE
N	Seated Height	33.8	35.9	38.0
O	Eye Height	29.4	31.5	33.5
P	Shoulder Height	21.3	23.3	25.1
Q	Elbow-Rest Height	7.4	9.1	10.8
R	Thigh-Clearance Height	4.8	5.6	6.5
S	Knee Height	20.1	21.7	23.3
T	Buttock-Knee Length	21.9	23.6	25.4
U	Popliteal Height	15.7	17.0	18.2
V	Forearm-Hand Length	17.6	18.9	20.2
W	Buttock-Leg Length	39.4	42.7	46.1
X	Buttocks-to-Inside-Knee	17.7	18.9	20.2
Y	Elbow-to-Elbow Breadth	15.2	17.3	19.8
Z	Hip Breadth	12.7	14.0	15.4
AA	Shoulder Breadth	16.5	17.9	19.4
BB	Span	65.9	70.8	75.6

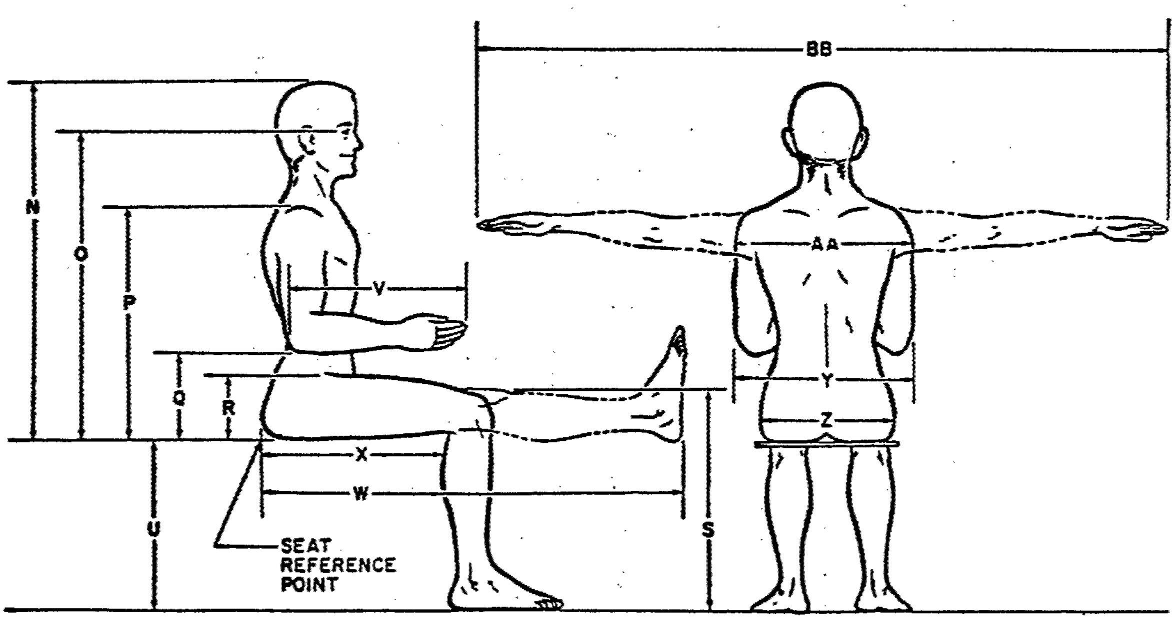


Figure A-14. Seated Body Dimensions

Table A-XI. Standard Console Dimensions

TYPE OF CONSOLE	Maximum Total Console Height from Standing Surface	Console Depth at Base	Suggested Vertical Dimension of Console Panel (including sills)	Console Panel Angle (from vertical)	Minimum Shelf Depth	Eye-Line-to-Panel-Base Distance	Writing Surface Depth Including Shelf	Minimum Knee Clearance	Foot Support to Sitting Surface[1]	Seat Adjustability	Minimum Thigh Clearance at Mid-Point of "J"	Writing-Surface-Shelf Height from Standing Surface	Seat Height from Standing Surface at Mid-Point of "J"	Maximum Console Width (not shown)
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1. Sit (w/vision over top)*	47.5"	Opt.	22"	15°	4"	16"	16"	18"	18"	4"	6.5"	25.5"	18"	44"
	54	Opt.	22	15	4	16	16	18	18	4	6.5	32	23	44
	58	Opt.	22	15	4	16	16	18	18	4	6.5	36	28.5	44
2. Sit (w/o vision over top)*	51.5	Opt.	26	15	4	16	16	18	18	4	6.5	25.5	18	36
	58	Opt.	26	15	4	16	16	18	18	4	6.5	32	23	36
	62	Opt.	26	15	4	16	16	18	18	4	6.5	36	28.5	36
3. Sit-Stand (w/standing vision over top)	62	Opt.	26	15	4	16	16	18	18	4	6.5	36		36
4. Stand (w/vision over top)	62	Opt.	26	15	4	16	16	NA	NA	NA	NA	36	NA	44
5. Stand (w/o vision over top)	72	Opt.	36	15	4	16	16	NA	NA	NA	NA	36	NA	36

* The range in "A" is provided to allow latitude in the volume of the lower part of the console; note relationship to "L" and "M".

[1] Since this dimension must not be exceeded, a heel catch must be added to the chair if "M" exceeds 18".

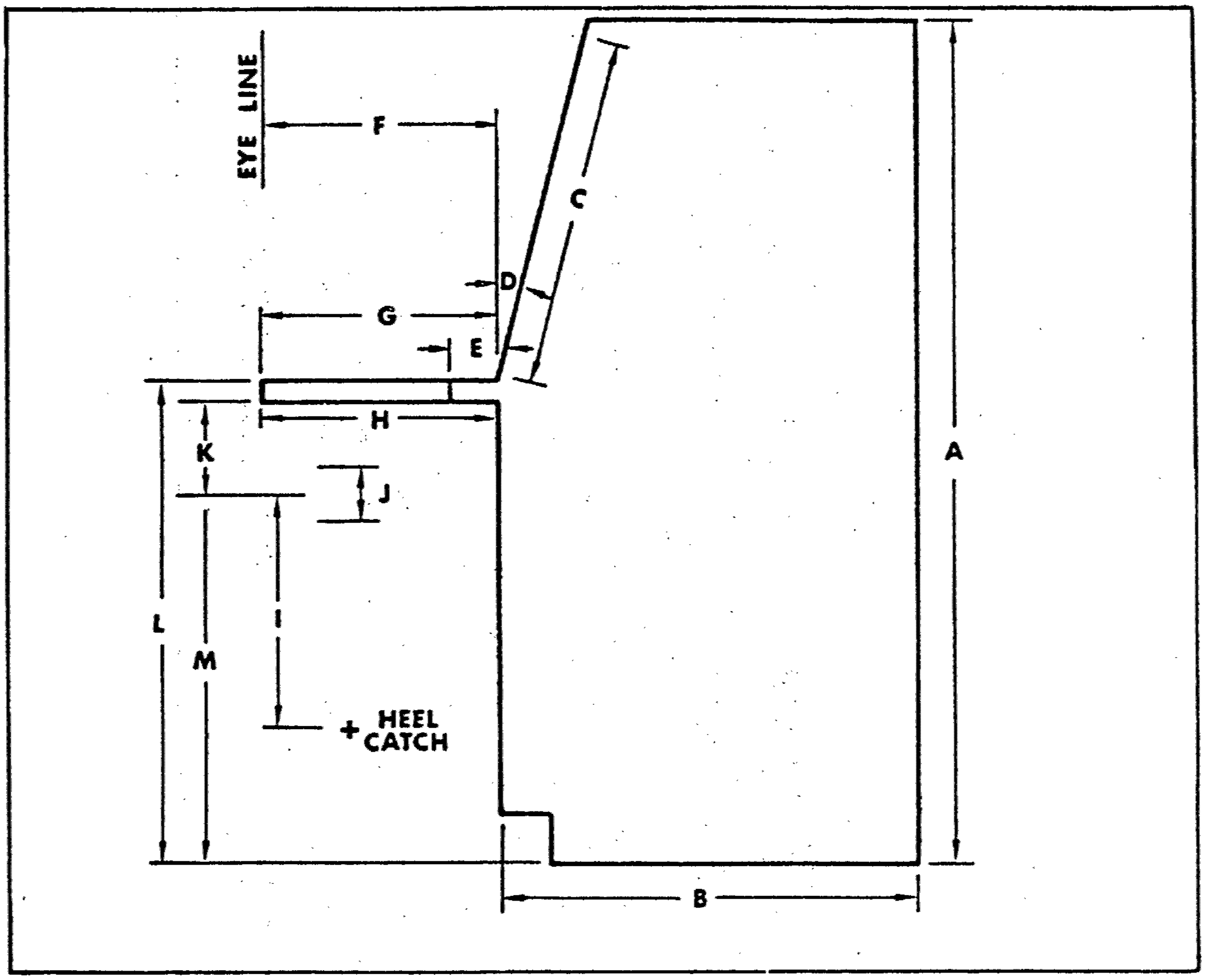


Figure A-15. Standard Console Dimensions

Table A-XII. Clearance Dimensions

KEY TO FIG. A-16	DIMENSION	MINIMUM	PREFERRED *	ARCTIC
5A.	Squatting workspace:			
A	Height:	48	--	51
B	Width:	27	36	40
	Display area:	--	27-43	--
	Control area:	--	19-34	--
5B.	Stooping workspace:			
C	Width:	36	40	44
	Display area:	--	32-48	--
	Control area:	--	24-39	--
5C.	Kneeling workspace:			
D	Width:	42	48	50
E	Height:	56	--	59
F	Optimum work point:	--	27	--
	Display area:	--	28-44	--
	Control area:	--	20-35	--
5D.	Kneeling crawl space:			
G	Height:	31	36	38
H	Length:	59	--	62
5E.	Prone work or crawl space:			
I	Height:	17	20	24
J	Length:	96	--	--

* The values for display and control areas represent vertical measurements from the floor.

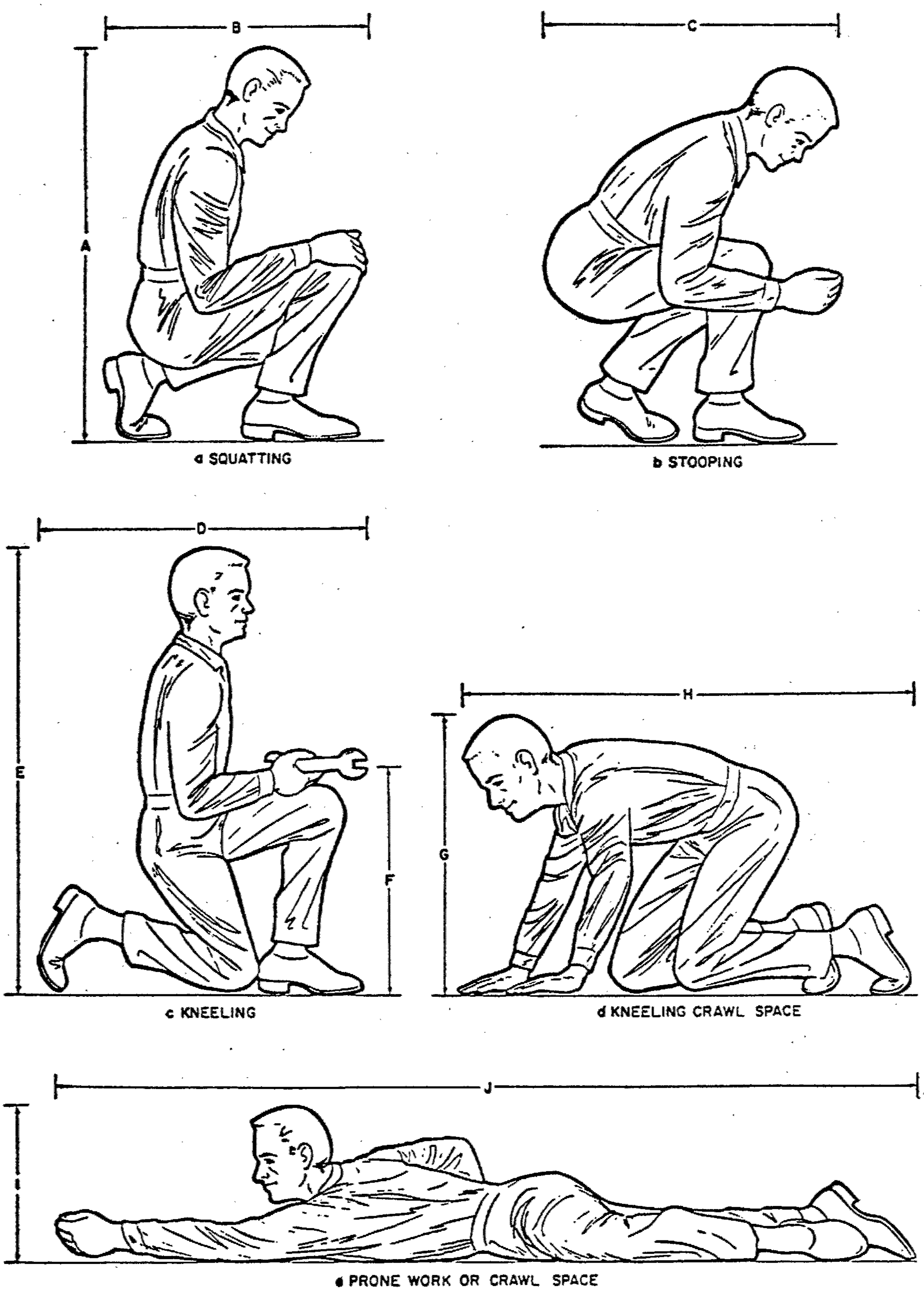


Figure A-16. Clearance Dimensions

3) Adjustable Dimensions - (seats, supplementary lights, telephone headsets, etc.) should be adjustable to accommodate the range of 5th through 95th percentile personnel.

2.7 OPERATOR COMFORT AND LACK OF INTERFERENCE

As the item under test undergoes normal commodity engineering tests to determine the extent to which the operating engineering requirements are fulfilled, it must also be evaluated during operational conditions with respect not only to the man-machine interface but from an operator comfort and lack of interference standpoint to determine if there are physical design features which, in actual operation, require modification in order to fulfill the human performance requirements. This information can be collected by using questionnaires and interviews.

Collecting valid opinion data by means of interview and questionnaire is an art which, if not properly applied, may yield deceptive or worthless information. Of equal importance is the motivation of the subjects, and the time, place and environment for conduct of the interview or administration or the questionnaires. For these reasons, it is highly desirable that interviews and questionnaires be prepared and conducted under supervision of a human factors engineer. General guidance on preparing and conducting interviews and questionnaires is available in References O and Q listed in paragraph 4 of this MTP.

The human error report form and the error-likely form should be used to collect information on human operating errors as they occur, and information on error-likely design features that can be recognized by an operator when he almost makes an error. These forms should be made readily available to all operating and test personnel so that they may be filled in when observations are fresh in mind and motivation is high. Their use must be explained by a human factors specialist. Personnel who will complete the forms should be assured that the forms will not be used to check anyone's personal efficiency, but are necessary for the collection of critical human factors data.

6.2.8 <u>Special Observational Tests</u>

Special observational tests for the exploration of specific human factors problem areas should be undertaken at the discretion of the test officer and the human factors engineer. When performed, such tests might include the following as applicable:

a. Operation of equipment or system by a human factors specialist crew.

b. Time and motion studies - the use of activity sampling techniques for the study of work units and operator activities, including time spent in various activities and sequence of performance.